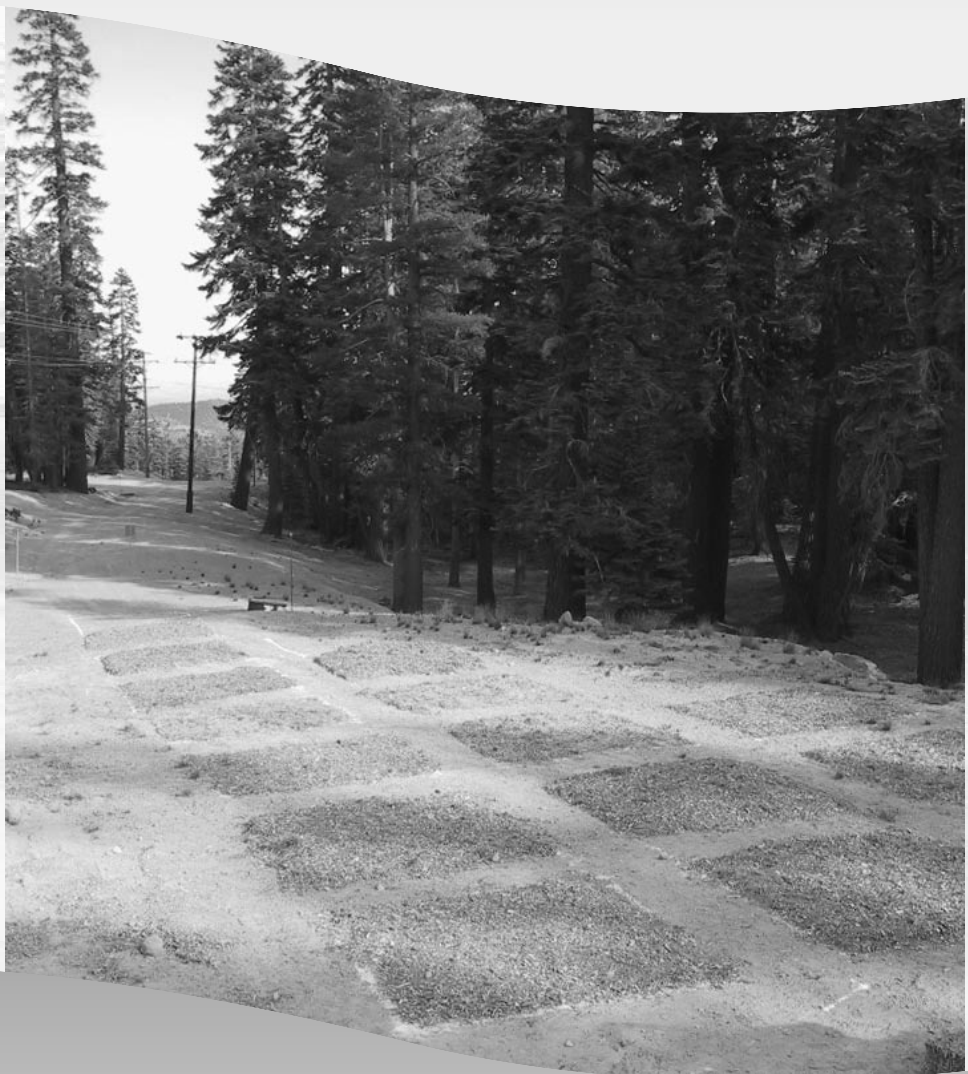
The California Alpine Resort Environmental Cooperative

presents

The Sediment Source Control Handbook

Preliminary Version – April 2005



Written by Michael Hogan,
Integrated Environmental Restoration Services

for The Sierra Business Council

in Cooperation with
The Lahontan Regional Water Quality Control Board

"All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in that community, but his ethics prompt him also to cooperate (perhaps in order that there may be a place to compete for). The land ethic simply enlarges the boundaries of the community to include soils, water, plants and animals or collectively: the land."

(Leopold 1949)

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Acknowledgements

The vision for the California Alpine Resort Environmental Cooperative (CAREC) emerged from ongoing discussions between Michael Hogan of Integrated Environmental Restoration Services, Martin Goldberg of the Lahontan Regional Water Quality Control Board and ski resort personnel. Many tensions over erosion issues between regulatory and ski area managers were due to the lack of good information on how best to control sediment in highly disturbed alpine areas. The idea to work together collaboratively to develop field trials was supported early by Harold Singer of the Lahontan Regional Water Quality Control Board, Amy Horne of the Sierra Business Council and a number of ski areas including Northstar-at Tahoe, Mammoth Mountain, Heavenly Lake Tahoe, and Alpine Meadows. With initial support from the Lahontan Regional Water Quality Control Board, a pilot program was launched to set up field plots and learn from different types of erosion-control treatments.

CAREC emerged from this pilot program as a collaborative partnership that includes representatives from ski resorts, Lahontan Regional Water Quality Control Board, US Forest Service, Tahoe Regional Planning Agency, consulting firms, Integrated Environmental Restoration Services and the Sierra Business Council. Time, resources, and technical input are all provided by the members plus outside 'experts' such as the Natural Resource Conservation Service (NRCS), the Nevada Resource Conservation District, and University of California Davis.

The key people who have worked throughout the pilot phase to help advance this program, install field trials, actively respond to earlier drafts of these pages, and commit to learning together about erosion control processes in disturbed alpine areas include:

Paquita Bath, Vice President, Sierra Business Council

Lou Cayer, Heavenly Ski Resort

George Cella, Lahontan Regional Water Quality Control Board

Todd Ellsworth, Ecologist, Inyo National Forest

Alex Fabbro, Planning Department, Mammoth Mountain Ski Area

Naomi Garcia, Environmental Scientist, TEAM Engineering & Management, Inc.

Martin Goldberg, Environmental Scientist, Lahontan Regional Water Quality Control Board

Melanie Greene, Scientist, Parsons Water and Infrastructure

Larry Heywood, Snow and Ski Safety Consultant

Michael Hogan, President, Integrated Environmental Restoration Services

Amy Horne, Research Director, Sierra Business Council

Eric Knudson, Squaw Valley USA

John Loomis, Director of Operations, Northstar-at-Tahoe

Erin Lutrick, Hydrologist, Inyo National Forest

Clifford Mann, Director of Mountain Maintenance, Mammoth Mountain Ski Area

Cadie Olsen, Trinity Environmental

Michael Schlaffman, Winter Sports Specialist, Inyo National Forest

Randy Westmoreland, Eastside Watershed Program Manager, U.S. Forest Service

Many thanks also to Karyn Erickson of the Sierra Business Council for the layout of this 2005 preliminary version of the Sediment Source Control Handbook.

Finally, developing collaborative programs that directly affect key businesses and water quality, requires a high degree of personal and institutional commitment. We acknowledge the commitment of all the CAREC team members to share their experiences, invest in experiments, and improve our understanding of sediment source control in ski areas throughout the Sierra Nevada.

I am grateful for the opportunity to work with this collaborative and serve as editor for this handbook. We look forward to continued cooperation on behalf of the Sierra Nevada.

Paquita Bath
Vice President
Sierra Business Council

Introduction to The Sediment Source Control Handbook

Sediment is a major water pollutant in the Western United States today. Wherever development takes place, disturbed areas are prone to sediment movement. Ski resorts are no exception. Large cut and fill, steep graded ski runs, can pose a serious threat to nearby waterways. Unfortunately, effective methods to control erosion for drastically disturbed alpine areas have not been well researched or documented. Despite a long list of 'BMPs', or recommended 'best management practices', attempts to stabilize disturbed alpine areas continue to produce inconsistent results.

To date, there has been little effort to develop a systematic approach — with specific goals, documented procedures, and ongoing monitoring — to control erosion in ski resorts. Projects are undertaken in a trial and error fashion, sometimes resulting in successful outcomes, and sometimes producing less than optimal results. While there is a broad range of knowledge across resorts, information sharing has been limited.

The California Alpine Resort Environmental Cooperative (CAREC) came together in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field plots, with various approaches to control sediment on site and thus reduce erosion. The purpose of the partnership is to use field plots to develop on-the-ground practices to better manage erosion and maximize sediment source control on ski area properties. The underlying philosophy is that a collaborative approach between land managers, field practitioners and regulators is the best way to develop an effective, functional and workable set of practices that parties can adapt to fit their needs while greatly enhancing their ability to control sediment in ski areas.

The group meets two to three times a year to share field trial results and challenges. CAREC uses an adaptive management process to plan, implement, and measure erosion control projects and then share information with other practitioners and regulatory personnel. This 2005 Handbook expresses the preliminary approaches and findings of an ongoing program to document cost effective and measurable improvements in sediment source control practices in Sierra ski resorts. The Handbook is made up of three sections:

Part I: Guiding Principles – provides an adaptive management approach to planning and implementing erosion control projects;

Part II: Technical Notes – describes treatment approaches as a starting point for developing better practices, procedures, and monitoring protocols.

Part III: Literature Review – references appropriate information for planners, practitioners, monitoring personnel and scientists involved in upland sediment source control projects.

Thanks to the State Water Resources Control Board, this pilot project will grow to incorporate field trails in at least six different ski resorts and substantial monitoring of sediment source control. An updated version of the Sediment Source Control Handbook, will incorporate monitoring results and CAREC's improved ability to control sediment in 2008.

Sierra Business Council

The Sierra Business Council (SBC) is the only membership-based regional organization devoted to securing the social, natural, and financial health of the incomparable Sierra Nevada. Founded in 1994, the award-winning SBC achieves its mission through leading-edge research & publications, on-the-ground programs and fee-for-service, and grass roots membership and community networking. Business, government, non-profit, and civic leaders use SBC to meet, share-ideas, gain access to resources and expertise, and put plans into action. Partnering with local communities, and in partnerships such as the California Alpine Resort Environmental Cooperative (CAREC), the Sierra Business Council helps communities plan for and achieve their visions for the future.

SBC is entering its second decade as an award-winning, regional business organization. In response to the enormous challenges facing the region, the Sierra Business Council helps Sierra communities work together to steer the region's economy, environment and communities in directions that ensure long-term prosperity. Recent accomplishments include:

- Being chosen by Governor Arnold Schwarzenegger for his prestigious 2004 Environmental and Economic Leadership Award.
- Developing the bipartisan coalition behind the landmark Sierra Nevada Conservancy bill, signed by the Governor, which invests in our natural, cultural, and historic assets.
- Training business and civic leaders in our world-class Sierra Leadership Seminar to improve individual professional skills while enhancing the civic infrastructure of our region.
- Securing funding for the Town of Truckee to explore development of a railyard brownfield to extend the vibrant downtown;
- Convening hundreds of Sierra business and civic leaders to address critical topics such as affordable housing, fostering creative communities, and the state of the Sierra.
- Publishing award-winning research documents like the *Sierra Nevada Wealth Index*, *Planning for Prosperity*, and *Investing for Prosperity* that are used every day to build sustainable wealth in our region.
- Partnering with the Edward Lowe Foundation to provide our members business and entrepreneurial resources plus a new SBC e-News & On-Line Networking tool.
- Developing a partnership of ranchers and conservationists to maintain ranching as a fundamental part of the Sierra's economy and landscape – conserving over 30,000 acres of working ranchland in the Sierra Valley;

SBC is proud to provide programs, research and documentation, such as the *Sediment Source Control Handbook,* that can stimulate residents and decision makers to work together to ensure that the Sierra Nevada remains one of the most desirable places to live, grow a business, and raise a family. The CAREC partnership will be expanded between 2005 and 2008 to ensure that our knowledge and understanding of sediment source control on steep alpine slopes continues to improve.

***For more information on the Sierra Business Council or to become a member, please visit www.sbcouncil.org*.**

The California Alpine Resort Environmental Cooperative

Sediment Source Control Handbook Part I

Guiding Principles

Preliminary Version – APRIL 2005

Written by Michael Hogan,
Integrated Environmental Restoration Services
for The Sierra Business Council
in Cooperation with
The Lahontan Regional Water Quality Control Board

Sediment Source Control Handbook Part I

Guiding Principles

Table of Contents

INTRODUCTION TO THE GUIDING PRINCIPLES

The California Alpine Resort Environmental Cooperative (CAREC) came together in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field plots, with various approaches to control sediment on site. Part I of the Sediment Source Control Handbook, consists of sixteen Guiding Principles for sediment source control in ski resorts in the Sierra Nevada. The full Handbook, also includes Technical Notes and a Literature Review that provide additional information and complement the Guiding Principles. The Guiding Principles are split into three sections: 1) Planning; 2) Implementation; and 3) Monitoring, to cover assessment, follow-up and information sharing.

Each Guiding Principle follows a general format for consistency and accessibility:

Goal: Describes the purpose of the Guiding Principle.

Description: Describes in greater detail, the Guiding Principle itself.

Example: One or more examples of the Guiding Principle. In some cases, the example also contains a solution or positive example of an application that supports the Guiding Principle. In other cases, the example describes a less than optimal situation that a particular Guiding Principle is meant to address.

Solution: In cases where the example describes a sub-optimal situation, the solution section describes an ideal application of that Guiding Principle.

Technical Notes: This section is listed when there are Technical Notes that provide more in-depth input for the Guiding Principle. Technical Notes describe treatment strategies that can be used to implement particular Guiding Principles. These Technical Notes are to be improved, upgraded and enhanced over time, as we learn from our on-the-ground applications.

Additional Suggestions: Describes any additional information, suggestions, etc., related to this Guiding Principle.

***For references cited please see the Reference List in the Literature Review (Handbook Part III)*.**

FRAMING THE PROGRAM: THE ADAPTIVE MANAGEMENT MODEL

The concept of adaptive management has been applied for centuries under a number of different names. Physical engineers have used this approach since the first structure or bridge was constructed to continually learn from mistakes and successes and improve designs. Adaptive management has a dual nature.

First, adaptive management is a philosophical approach toward resource management that acknowledges that we do not completely understand the system that we are dealing with. It acknowledges that we will proceed with a project or program using existing information while we gather the knowledge that we lack.

Second, adaptive management is a structured decision-making process that includes the following components, usually in stepwise and cyclical fashion:

- Articulate project goals, outcome or success criteria
- Collect existing knowledge and practices relative to achieving the goals
- Identify information gaps and related research needs
- Develop a strategy and apply knowledge and relevant practices towards achieving the clear goals
- Develop a clearly-defined and defensible monitoring program to determine whether the goals are being achieved
- Negotiate a pre-defined management response if the goals are not met.
- Reassess and improve practices and reconsider the goals or outcomes.

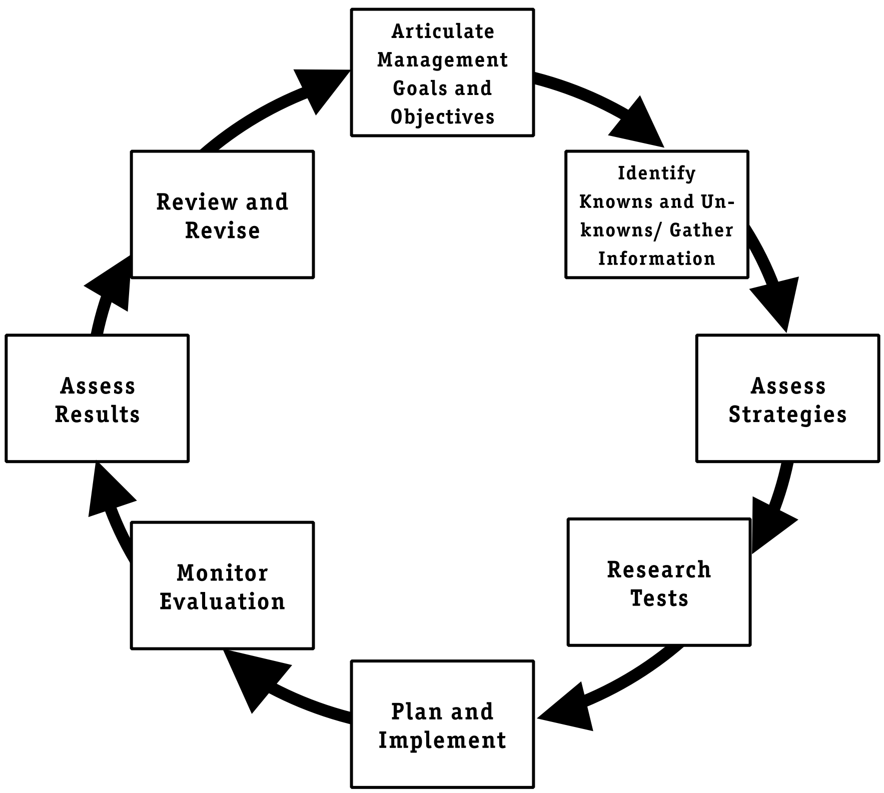


Figure 1: The Adaptive Management Model

The CAREC partnership chose to use an adaptive management model as its framework (Ringold, Alegria, et al. 1996; Elzinga, Salzer, et al. 1998; Chiras 1990). Figure 1 represents the adaptive management model graphically. It is used throughout the document to illustrate where a particular step or practice falls within this model.

Section One: Planning

Guiding Principle 1: Identify The Need For Action and/or The Problem

Goal: To clearly understand both the need, or 'trigger', for taking action and the specific problem(s) being addressed.

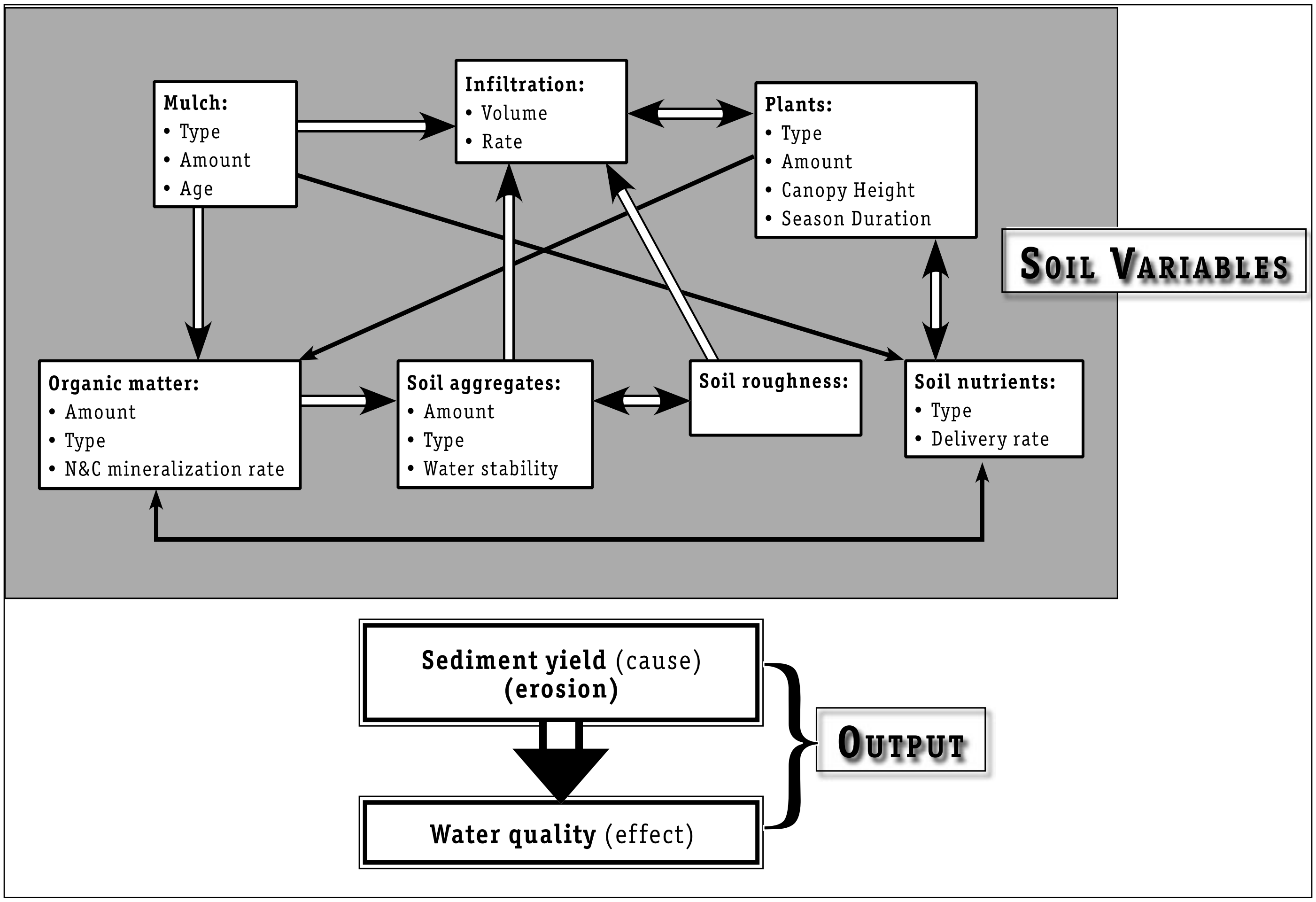
Description: The first step is to: 1) decide or understand why action is being taken; and then 2) identify what the problem is. The need for action is often straightforward. Identifying the nature of the problem is often more difficult. Action is sometimes taken without understanding the true nature or scale of the problem and thus may result in solutions that address the symptom, but don't directly resolve the source of the problem.

- Action may be triggered by identification of a water quality/erosion problem, for instance rilling of a ski run or a mass failure (landslide). It may be triggered by regulatory agency request or any number of other reasons.
- When the need for action is understood, it is critically important to understand the nature of the problem as completely as possible.
- It may take time to fully understand the nature of the problem. Time spent understanding the problem(s) early in the planning process usually pays off because there is a much higher probability of focusing resources (people, equipment and money) on the causes of the problem, rather than the symptoms.

Example: A ski run is heavily rilled. Both management and the local USFS representative identify the rilling as a problem. The area is re-seeded, mulched and irrigated. Vegetation is established. However, after a summer thundershower, rilling is again noted.

Solution: Rilling was a problem. A breached set of 5 waterbars above the area of concern indicated a more complex source of the problem. In this case, the lack of water infiltration in the soil across the entire ski run resulted in the surface runoff. The runoff was not stopped by either the vegetative cover or the waterbars. This area will probably need to have the soil treated so that infiltration rates are increased and surface runoff is decreased.

Additional Suggestions: The erosion model below may provide a good starting point or checklist to help identify which elements of the erosion control process may be failing.



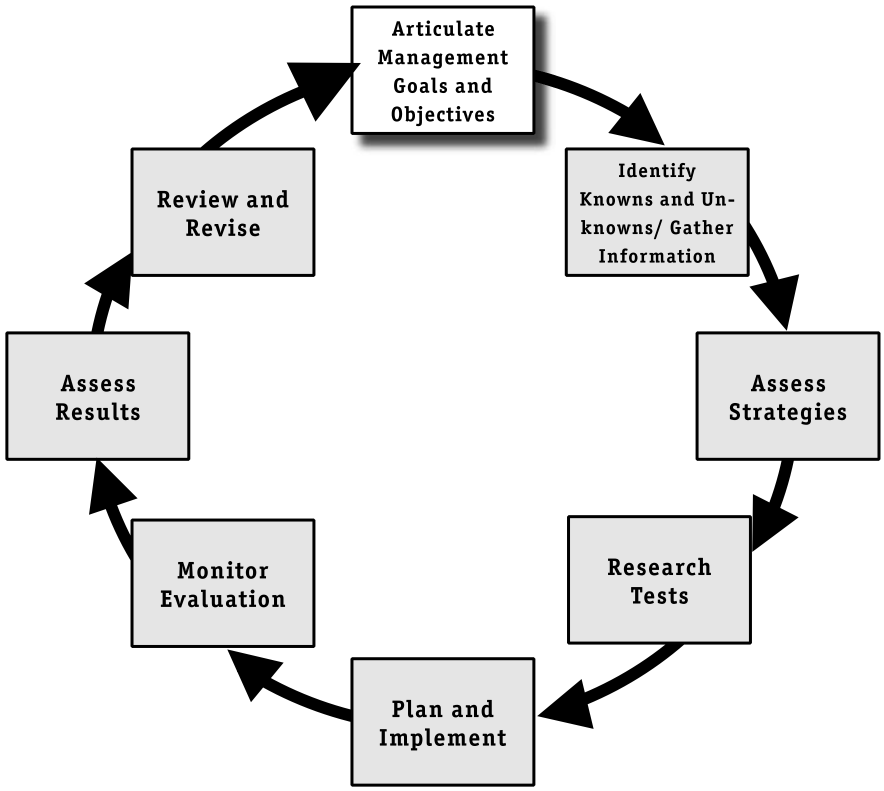
Erosion Model

GUIDING PRINCIPLE 2: STATE PROJECT GOALS AND OBJECTIVES[1]

Goal: The goals of this section are twofold:

1) Goals: to define in general terms, and as inclusively as possible, the desired project outcome;

2) Objectives: to define, in specific and measurable terms, desired project outcomes based on stated goals.



Description: Developing and defining project goals allows the project planner to define the intended outcomes. Project goals and objectives are reference points that define the rest of the project. These goals and objectives will ideally be linked directly to addressing the problem(s)/need for actions that were identified in Guiding Principle 1.

Goals and objectives refer to similar concepts but differ in detail. That is, goals are broad, general and 'non-specific' statements such as "controlling erosion on the GS Run." Objectives are the more specific

[1] The terms 'Goals' and 'Objectives' can be confusing. For the purpose of this document, we use terminology that has been adapted from Stanley, John T. (2004) 'Ecological Restoration and Watershed Stewardship Planning Terminology', Tahoe Regional Planning Authority.

If you don't know where you're going; any old road will get you there.

Will Rogers

measurable manifestation of that goal such as "developing minimum infiltration rates of 1 inch per hour" or "developing a native grass stand on the GS Ski run of 25% plant cover in three years."

Goals should be:

- Clearly stated and direct
- General and non-specific
- Inclusive (sediment control AND wildlife habitat maximization)
- Flexible enough to persist over time

Objectives should be:

- Specific
- Measurable
- Realistic and attainable (physically and economically)
- Directly related to the problem
- Time specific (state when and how long?)

Success criteria are specific measurable elements directly tied to project goals and objectives (*see Guiding Principle 3*).

Example: While goals are relatively non-specific, they can be problematic if not clearly related to the source of the problem. For instance, a goal such as "Revegetate the GS Slope" is vague and may not be the appropriate solution for sediment source control in that area. Poorly framed goals and objectives are difficult or impossible to measure, thus not contributing to an improved understanding of sediment source control.

Solution:

Goals: To control erosion [on an eroding ski run] through soil treatment and native vegetation community establishment.

Objectives: To establish an infiltration rate on the GS Run to levels similar to (within 10% of) a native forested area of similar slope and aspect in the vicinity, and to establish a native plant community of 25% vegetative cover within three years.

Additional suggestions: The process of defining goals and objectives can be simple and involve only a couple of individuals. With larger projects, it may involve a great many stakeholders. Generally, involving as many interested parties as possible, as soon as possible, in the planning process minimizes unforeseen roadblocks later in the process.

GUIDING PRINCIPLE 3: DEFINE SUCCESS

***Goal:** To define success in quantitative terms wherever possible so that the project outcome (at a specific point or points in time) can be clearly measured and understood.*

Description: Success is defined by quantitative or at least clearly identifiable specific criteria. Criteria should reflect whether the project goals and objectives have been met. It should be as clear as possible whether the success criteria listed are direct measurements, such as 'visible rills' or indirect measurements such as cone penetrometer measurements as an indication of whether soil is too compacted to infiltrate water.

Success criteria must be achievable and practical. These criteria will generally include a number of elements, for instance, plant and mulch cover, soil nutrient status, soil density (cone penetrometer measurement), and visible soil movement.

Example: A project is being planned whose goals include both erosion control and aesthetic or visual impact improvements. Success criteria may include plant cover, mulch cover, adequate soil nutrients, no signs of visible erosion, low soil density, native flowering shrubs and forbs and no bare areas.

Solution: Each of these elements will be assigned a number and quantifiable objectives. Based on the differing objectives, each project will probably have different, site and project specific success criteria.

Additional suggestions: Success criteria often represent indirect measurements of performance. Cummings (2003, 4:S79-S82) and others have suggested that success be linked to functional elements such as hydrologic function (infiltration, water storage, etc.), nutrient cycling (soil nutrients, plant potential for cycling, etc.) and energy capture (plant and microbial biomass production and carbon processing), rather than just measuring or assessing the above ground plant community. This change in emphasis may be much more effective in indicating long-term project success.

Management response: A management response describes actions that are to be taken when success criteria are not met. These actions can be listed on a success criteria matrix. This process places the responsibility for action in the hands of the land manager and typically does not require regulatory agency oversight. At this time, there are no set standards for management responses. However, a proactive and agreed-upon set of management responses can maximize the efficiency of both agency and land managers, making interactions more straightforward and positive since follow up is agreed upon in advance and not suddenly enforced through crisis regulations.

GUIDING PRINCIPLE 4: ASSEMBLE THE PROJECT TEAM

Goal: To identify and assemble appropriate planning and implementation personnel that will assure the best project outcome.

Description: An effective plan requires personnel with an understanding of: **a)** the nature of the problem; **b)** how to fix the problem; and **c)** how to effectively carry out the plan in the field. Project team make-up and size vary greatly from project to project and from area to area. Simple projects can be managed with a small team while larger, more complex projects, may require a broad range of expertise. An effective team will include, at a minimum, a team leader/project coordinator and a person or persons with expertise directly relevant to the problem areas. (A list of potential team members is included in the sidebar.)

4.1: Assemble a Team Leader/Project Coordinator

The most basic element of a team structure is the team leader, project coordinator and/or contact person. In a simple project, this person may also have the expertise to plan and implement the project. In more complex projects, this person will be responsible for assembling and coordinating the team and should be the central contact point for both the team and the stakeholders.

4.2: Assemble a Team with Appropriate Expertise

Appropriate expertise is critical. A civil engineer will not usually have the expertise to address sediment source control issues and a botanist will not usually be able to design a retaining wall. The nature of the problem or project will drive the expertise needed.

Example 1 - Small scale: A ski run has been identified as not meeting specific success criteria. It shows evidence of rilling, a large, bare area and two failed waterbars. The mountain manager and the Regional Water Board representative discover these conditions during a routine walk-through. They agree that the mountain manager will provide the Regional Board with a plan to repair the problems and then, upon review, implement the plan.

The mountain manager contacts the erosion control manager on staff who has 15 years practical experience and several courses in erosion, botany, soil processes, etc., and asks her to develop a plan. This plan is developed, submitted to the Regional Water Board and approved. The erosion control manager then gives direction to the 3-person crew to carry out the plan as written.

Functionally, this 'team' is made up of 5 people: the project leader/coordinator (mountain manager), the planner/implementation director (erosion control manager) and the implementation team (3- person crew).

Example 2 - Large scale: A new ski run was defined in the Ski Area Master Plan of 1985. Funding has been acquired to construct this run, which skirts a wetland. Management has begun planning this year's construction schedule. In this case, the ski area planning director is assigned project coordination. This project will be large and complex and will require planning, permitting, wetland regulation, civil engineering, biology, soil, revegetation/ erosion control and other expertise. Planning will be challenging to coordinate. Further, part of the team may include community or interest group members who have general or specific concerns (such as intrusion into potential wetland habitat) that could present roadblocks later in the project if not addressed up front. The project coordinator will choose some or all of the expertise from the sidebar list, as appropriate.

Additional suggestions: Assembling and coordinating an effective team is time consuming and challenging. However, a great deal of project experience shows that when done properly, this process can ultimately lead to a more effective project on the ground and can minimize challenges and/or roadblocks to project implementation.

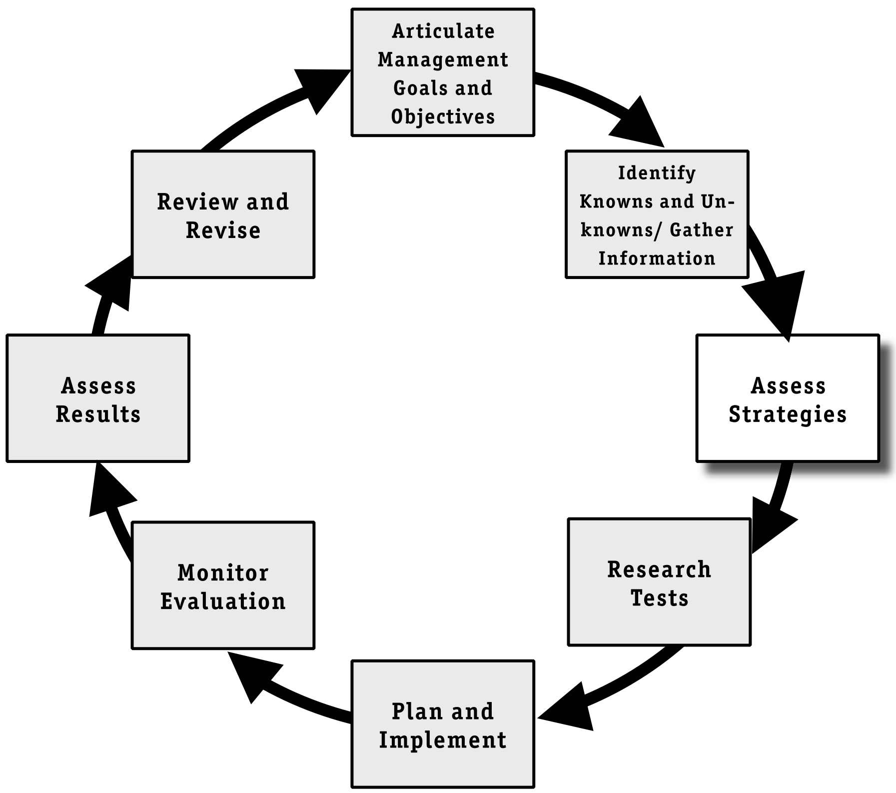
Potential Expertise/ Team Members

Planning
Ski area managers
Project manager(s)/coordinator
Planners
Technical
Erosion control specialist
Revegetation specialist/Botanist
Geomorphologist
Watershed specialist, watershed hydrologist
Restoration specialist
Engineer
Wetland specialist
Ski run construction specialist
Ski area implementation personnel
Regulatory
USFS
Water Board staff
County staff (engineering and/or permitting)
Stakeholders

Note: a team may include some or all of the above listed members. Some 'members' may have a limited role. For instance, county staff may simply advise what permits will be needed and will then review the plans to make sure they adhere to county ordinances. Implementation personnel should review plans to ensure they are feasible. Engineers and erosion control specialists may be involved all through the process. Further, individuals may have two or more areas of expertise, for instance erosion control, revegetation and watershed hydrology.

GUIDING PRINCIPLE 5: ASSESS STRATEGIES FOR A SITE SPECIFIC IMPLEMENTATION PLAN

Goal: To develop a sediment source control implementation plan that is based on specific site conditions and that targets clearly identified outcomes.



Description: Develop a plan that addresses existing site conditions, and defines a process for meeting the desired project goals, objectives and success criteria. The following list details steps and considerations for developing that plan.

5.1 Assess site conditions

Document existing conditions in order to determine next steps and measure results.

Example: Cone penetrometer readings indicate how compacted the soil is, in turn, providing guidance on whether tilling or other soil physical treatment will be required. Similarly, a nutrient analysis of soil samples will indicate the potential for plant growth and the need for amendments to rebuild the soil.

5.2 Choose a reference site

Assessment of a suitable reference site presents a 'standard' or reference to aim for.

Example: Soil nutrient analysis of a nearby reference site which supports adequate native vegetation will suggest the appropriate level of nutrients needed on the ski slope. Vegetation analysis of a reference site will suggest what vegetation community can actually be supported in this environment. Reference sites may be a native site or a previously treated site that is performing according to success criteria.

5.3 Develop a plan based on the two previous steps

The project plan is based on site conditions and information found in nearby reference sites. This allows the plan to be site specific and achievable.

Example: a project site is analyzed for both soil density and soil nutrients. The project site has a soil density maximum of 500 psi (pressure per square inch) to a depth of 6 inches at which point the penetrometer stops. Total soil organic matter is 0.7% and total N is 350lbs/ac. The reference site, a revegetated site nearby with a high level of plant cover, has penetrometer readings of 275 psi to a depth of 16 inches. Soil nutrient analysis indicates 3.75% organic matter and 1800lbs/ac of total N. This baseline clearly indicates that soil tilling and organic matter amendment will be required on the project site.

5.4 Maintain natural conditions to the greatest extent possible

It is important to maintain 'natural' hydrologic, nutrient cycling, topographic and other physical conditions to the greatest extent possible.

Example: During construction, drainages will ideally be left unaltered. Topsoil will be left in place or salvaged and replaced. Where one or more of these conditions is altered, the plan should re-create the natural conditions to the greatest extent possible. For example, if a drainage is intercepted and/or altered during the construction of a ski run, a new drainage should be constructed that mimics the pre-disturbance drainage as much as possible. A road constructed across a hillside interrupts the dispersed surface runoff. The road should be outsloped and drainage should go across the road to encourage ongoing dispersion. Capturing the hillside runoff, by contrast, would concentrate water and build up a great deal of erosive energy.

5.5 Consider potential alternative treatments

More than one potential treatment should be considered. Treatment alternatives can be developed from the Technical Notes or other appropriate, field-tested tools. Time, intensity of the problem, and available resources will define which tools would be most effective.

Example 1: A steep slope is eroding and depositing sediment near a stream. Alternative treatments may include silt fencing, straw bales, full soil-restoration treatment or mulching. Given the proximity to the stream and the temporary duration of some of the potential alternatives, the full soil-restoration treatment is likely to be the most effective, though most costly of the treatments.

Example 2: A nearly flat area erodes during high intensity rainfall events. This area is 500yds from the nearest creek and runoff must travel through a great deal of vegetation to reach the creek bank. Alternatives include full soil-restoration treatment, mulching, tilling of wood chips, straw bale barriers, or a silt fence. Given the distance to water, the flatness of the slope, the easy availability of wood chips, and the fact that budget constraints exist (it's a ski area), the project manager chooses to till wood chips into the soil to increase infiltration and mulch the soil surface with no further treatment. If this treatment meets the success criteria (no measurable erosion off site), this would be an effective and cost-saving alternative.

5.6 Incorporate tests where information gaps exist

When choosing treatments, planners will encounter information gaps with regard to materials, treatments, time frames etc. Wherever possible, tests can be overlaid on treatments to help answer those questions and fill information gaps. In this way, each project adds tour knowledge base and furthers future project outcomes.

Example: A recent erosion control conference presentation showed that a specific fabric significantly reduced erosion during year one of a large project in South Carolina. A steep road cut near Mogul Lift has been eroding and management has decided to address the problem. The budget is too small to apply fabric to the entire area. You are also not sure how the fabric will respond to snow over the long-term and want to test it in local conditions. You are able to afford 500ft of the fabric, which you apply to one portion of the project. In the subsequent 3 seasons (the time portion of the 'success criteria') you monitor the entire site, comparing the fabric area to the standard treatment, looking for signs of erosion and measuring plant growth for differences. This test was inexpensive and provides valuable information on whether the fabric contributed to the success criteria and its usefulness in high alpine areas.

5.7 Choose appropriate treatments

The treatment alternative(s) that are chosen should be adequate to meet project goals and objectives, should be field tested, and should be aligned with project budget parameters.

Example: In the previous two examples, if a silt fence had been chosen, it is unlikely that effective project outcome would be achieved. Silt fences are temporary structures, have not proven effective in snow areas, and fail to address root problems. CAREC is committed to avoid these 'do something, even if it doesn't work' treatments, by rigorously testing alternative approaches.

5.8 Identify and address potential threats to project success

Impacts on treated sites such as post-project vehicle or foot traffic, skier impacts in areas with low snow, lift tower access, or potential ATV traffic need to be considered and addressed. If impacts cannot be eliminated, protections must be put into place if overall project goals are to be met.

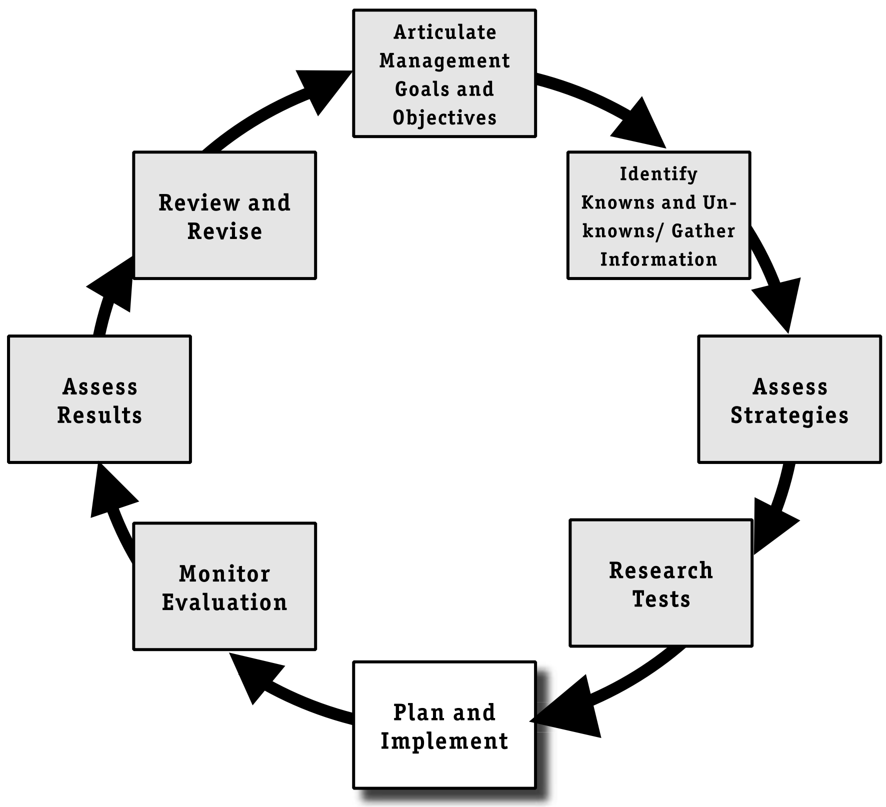
Technical Note 1 and 2: Assessing Site Conditions

Section Two: Implementation

***Section Overview:** This section describes processes that will assure maximum success when applying sediment control techniques in the field. The Guiding Principles in this section assume that a carefully constructed plan has been developed.*

GUIDING PRINCIPLE 6: TRAIN STAFF AND ASSOCIATED PERSONNEL

Goal: To increase the level of awareness and understanding of the sediment source control program for all ski area personnel from implementers to resort personnel uninvolved in project treatment activities. This Guiding Principle is for internal resort protocols and practices.



Description: Training is critical to raise awareness of sediment source control as well as to ensure no post-treatment disturbances disrupt the projects. Implementation staff need to be fully versed in project goals and strategies. General resort personnel must understand travel restrictions and ways to avoid inadvertently harming treated areas. Strategies need to be developed and shared regarding outside impacts, such as by mountain bikes, ATVs and so on. With full staff support and understanding, treatment sites will be better managed. Further, when personnel understand erosion processes and goals, they can help spot, and possibly repair, small problems such as water bar breaks or clogged culverts.

Example 1: A small ski area maintenance crew is spreading compost on the Downhill Run so that it can be tilled in and revegetated. They haul the compost to the run and push it over the side, ‘covering’ the run as told. Unfortunately, the compost is 9 inches deep at the top of the run and 1 inch deep lower down. Remedying this mistake costs an additional four hours for three people.

Solution: A 15-minute training session that explains the soil restoration process and why compost needs to be spread evenly for tilling would help ensure the crew distributes the compost effectively the first time.

Example 2: The Lower Concourse area near lift 500 has just been recontoured and replanted along an old seldom used, lift access road. To access a new area designed for summer concert activities, Joe Lifto, a long-time lift mechanic, drives straight across the treated area in the approximate location of the old road. This ruins the treatment, and requires new soil tilling to get rid of the 4-wheel drive ruts, plus the expense and time needed to recontour and replant.

Solution: A memo sent to all personnel, communication with department heads and a directive from the Operations Manager indicating that all treatment areas are strictly off limits. The memo details the accepted driving areas. A system of personal accountability will help achieve these goals.

Additional suggestions: This proactive step, while requiring more up-front time, is essential for managing treatment sites to stabilize soils. A regular communication process from sediment source control personnel to the rest of the staff can help to meet goals and gain widespread support for the program when they understand the purpose and strategies being implemented on the treatment sites.

Guiding Principle 7: Oversee and Document Activities

Goal: To oversee implementation of erosion control activities and to document installation of treatment sites in the form of 'as-builts'. Precise documentation allows for useful ongoing monitoring to learn from the various treatments.

Description: Implementation oversight, sometimes called 'implementation monitoring', assures that project plans and specifications are applied as written and intended. This step is also used to make adjustments to specifications in the field, where plans are not feasible as written, or where some other method may work better.

During implementation oversight, notes, drawings and photographs that explain what was done, how it was done, when, who was involved, any changes to the original plans and ideas for alterations or method improvement should be documented. The erosion control manager has to ensure that implementation is tracked, however delegated, and then check for accuracy and a consistent format across treated areas.

Example: Oversight: A manager instructs his crew to seed the Uphill Down Run after a snowmaking line is installed. The manager is not able to supervise the project, which requires coordination between the snowmaking installers and the reveg crew. The snowmaking line is installed and backfilled and the reveg crew hydroseeds the area. The following day, equipment movement tears up the hydroseeded area.

Solution: Oversight: Better coordination or direct oversight of this project would have resulted in only part of the area being treated. The crew was unaware that lateral lines were being installed and therefore hydroseeded areas that were to be torn up. Better coordination would have saved 5 hours of labor and $700 of seed and fertilizer.

Example: Documenting: Erosion control treatment is installed along the length of a full ski run, with two test areas along one side where a new type of compost and two seed mixes are used. The project manager doesn't record or photograph the process nor indicate the location of the test plots on a map. She is sure she will remember this simple layout and will record it before winter begins. However, she forgets due to the onset of an early winter. During the winter, she takes a beach break and disappears over the Bermuda Triangle, never returning to work. The following season, no one knows which treatment went where or how much compost was applied.

Solution: Documenting: The project manager uses the Site Assessment Data Sheet (Technical Note 2) and added additional information about the treatment. . The following season, her replacement knows exactly what was done, where it was done, how deep tilling was done and the exact seed mix. He also has photos of the process so he can better understand how things were implemented.

Technical Note 2: Site Assessment Data Sheet

Additional suggestions: Project oversight can be the difference between success and failure. Project documentation and tracking can be the difference between knowing why a project did well and having no idea why it succeeded or failed. Both elements take extra time but significantly reduce wasted resources and frustration.

GUIDING PRINCIPLE 8: MAINTAIN, MAXIMIZE AND/OR RE-ESTABLISH HYDROLOGIC FUNCTION

Goal: To maintain or create a situation where hydrologic function, especially surface hydrology, is stable and does not degrade the watershed.

Description: Erosion is influenced by interrupted and improperly designed surface water patterns on ski runs, roads and elsewhere. Planning for and implementing surface hydrology and flow patterns is critical whenever new developments disturb the soil. The most effective approach is to leave existing flow patterns undisturbed and design around them. Where that is not possible, a high level of practical planning is needed to address and accommodate existing and potential water flows.

Example 1: An existing road carries water during spring runoff, resulting in severe rilling and erosion to a nearby stream. A plan is developed to place waterbars along the road to direct water into existing roadside vegetation before it builds up volume and velocity. However, as water is redirected, it erodes fragile soil beneath the existing roadside vegetation, causing even more erosion and destabilizing the hill slope.

Solution: This is an insidious and difficult issue. Some combination of settling/distribution areas, rock lined, vegetated outfalls or other elements should be considered. When waterbars are installed, they must be appropriately placed with frequent spacing, and be properly constructed and maintained. They also must be able to outfall into a stable area and/or outfall structure.

Example 2: A new ski run is cut down a steep north-facing slope that holds snow late into the spring. This slope was logged over 40 years ago and remnants of 4 logging roads that transected the slope still existed. The ski run was cut and successfully revegetated. Five years later, large, 3-foot deep headcuts and trenches can be seen from across the valley during the summer. Large amounts of sediment were deposited into the nearby creek, reducing summer flows and essentially ruining the little remaining fish habitat.

Solutions: Two elements of this situation contributed to the problem. The most obvious is the capture of flows from the 4 roads by the ski run. This contributed to high levels of surface flows. In this case, the roads were eliminated, surfaces restored, and the road capture of runoff water eliminated. A related and more subtle issue is that, in the construction of ski runs, a great deal of compaction occurs, particularly in high-clay soils. Compaction results in very low infiltration rates and greatly increases sheet flow, which also contributes to sediment movement throughout the entire ski run. This type of erosion is difficult or impossible to see until rills and gullies begin to form. The solution was to add organic matter to the soil surface and till the run in strips across the run face to maximize infiltration. This process effectively reduced surface flow by 600%, thus reducing or in many cases, eliminating erosion.

Additional suggestions: The design for effective hydrologic function related to roads, ski runs and other disturbance areas needs a great deal of further investigation. Standard BMPs do not tend to deal with this issue in a systemic manner.

GUIDING PRINCIPLE 9: MAXIMIZE SOIL FUNCTION

Goal: To create a soil physical and biological environment that optimizes water infiltration and plant and soil microbial communities.

Description: Soil is the foundation of terrestrial ecosystems. Soil physical and biological status will determine, to a large extent, how erosion-resistant a site is. Maximizing soil function is done through:

- soil sampling to determine soil density, soil nutrient content and cycling potential;
- soil amendment (organic matter) addition where suggested by soil samples; and
- soil tilling where density is high and/or where organic matter is to be incorporated into the profile.

Mulch is also extremely important in soil function (*See Guiding Principle 10*).

Example: Two adjacent ski runs are constructed. The planning team has just attended a seminar where it was suggested that tilling and organic matter amendment is important in controlling erosion on ski runs. They instructed the maintenance department to try these two techniques. On one run, they spread three inches of compost and left everything else as they had always done. On the other run, they tilled the soil to twelve inches and then applied standard seed mix, fertilizer and straw mulch. Two years later, they received a notice of violation from the State Water Control Board for excess phosphorus and nitrate in the nearby creek and for excess sediment in another creek.

Solution: In applying compost to the first area, there were two problems: 1) they didn't know what the actual nutrient status was. It turned out that there were adequate nutrients in the soil and that compost wasn't really needed. By not tilling and by adding excess nutrients, what was added ran off of the compacted surface and into the creek, causing a large algae bloom. In the other case, the soil was tilled but due to low organic matter in the soil, it recompacted within two seasons, resulting in a large amount of surface flow and a 10 yd^2 mass movement that placed a large amount of sediment in the creek. The solution would have been to sample the soil, add compost where NEEDED, and till both runs. This would have resulted in increased infiltration, increased soil root penetration and more sustainably stable ski runs.

Technical Note 3: Soil Physical Preparation

Additional suggestions: Our understanding of soil processes and soil amendments for steep wildland areas is in its infancy. Information gaps on soil function present a range of opportunities for testing.

GUIDING PRINCIPLE 10: MULCH AND SURFACE PROTECTION

Goal: To provide surface cover and protection as the first line of defense against erosive forces.

Description: Surface cover or mulch, is a critical and, perhaps, the most cost effective sediment source control treatment. Mulches vary widely in both form and function and include wood fiber mulch, straw, wood chips, pine needles and erosion control blankets. Mulch should be put on heavily enough to control surface erosion and will ideally be long lasting.

Mulches are known to provide some or all of the following benefits:

- interception of raindrop energy;
- reduction of surface water flow velocities, reducing erosive forces and increasing infiltration;
- filtration of sediment entrained in surface water flows;
- long-term, slow-release nutrient source;
- infiltration by increasing soil biologic activity/soil aggregation;
- buffering of soil temperatures;
- reduction of evaporation from soil; and
- aesthetic benefits

Example: Mulches vary widely. Bonded fiber matrix is a wood fiber mulch with polyester fabrics added. Wood chips or tub grindings are popular and pine needles have gained wide acceptance as a mulch that also results in a natural looking surface after application.

Solution: Mulch should be linked to the intention of the project and the service life of the mulch. If a short-term (1-2 year) mulch such as straw is used, consideration should be given as to whether the soil and plants established in that time frame will survive without mulch or need additional applications.

Additional suggestions: Mulch use has changed a great deal in the past ten years with more emphasis being placed on long-lasting mulches. A great deal of the garbage waste stream in a ski area during certain times of the year may consist of materials that can be used as mulch. More work needs to be done in this area.

GUIDING PRINCIPLE 11: VEGETATION

Goal: To choose the appropriate plant materials to advance project goals.

Description: While vegetation was once considered the primary defense against erosion, the CAREC literature review and recent research suggests that vegetation, while important, is one component of an overall system of erosion control elements.

Vegetation considerations are complex and knowledge of native plant species is limited. Considerations for choosing plant material will include some or all of the following:

- Is the plant species easy to establish?
- Is the plant species appropriate for the site?
- If planted from seedlings, what is the survival rate?
- Does the plant mixture require additional irrigation and if so, has that irrigation been planned for?
- Does the species regenerate itself?
- Is it an indigenous native species?
- Is the plant material of choice available and in sufficient quantities?
- Does the chosen material fit budget realities?
- Can the species survive in a ski run situation, especially with low snow pack?
- Does the species fit with the desired aesthetic?
- Does the species stabilize the soil?

Example: A steep-cut slope was revegetated with expensive native shrub seedlings. Planting was difficult and required additional irrigation. Within 2 months of installation, a late summer shower delivered 1.25 inches of precipitation in less than 45 minutes. Following the thundershower, the entire slope was covered with rills. Approximately 1/3 of the plantings were washed away.

Solution: Habitat or aesthetic goals were confused with soil stabilization goals. In this case, a grass mixture with infrequent irrigation during the first summer would have provided the soil with surface protection and soil strength though root structure. Native seedlings are often less effective than grass for soil stabilization in the early period. A good seeding with grass and a robust mulch cover (assuming adequate infiltration) would have provided protection to this area. Seedings could then have been incorporated in subsequent years to grow into a long-term role for stabilizing the slope with deeper root penetration.

Technical Note 6: Plant Materials

Additional suggestions: Little is know about many native species. Planting and tracking survival rates of different native species on each project would be a valuable input into our learning process.

GUIDING PRINCIPLE 12: PROTECT PROJECT AREA FROM FURTHER DISTURBANCE

Goal: To reduce or eliminate post-project disturbance to maximize treatment benefits.

Description: Once an area has been treated, additional disturbance is likely to re-compact the soil, reduce infiltration, and destroy vegetation. Protection against post-treatment disturbance is critically important for project success.

Example 1: Bubba's run had just been completed and treated. Vegetation was just beginning to sprout when Bubba himself, a much loved and now retired staff member, decided to take a quad trip to see what his run looked like in the summer. He took the summer road to the top of the run and in a fit of pride and exuberance, headed straight down the run. The irrigation technician/ snowmaker, had just finished watering the run so Bubba's trip down was a bit slippery, requiring some skidding. The next spring, two large rills/gullies were visible from run top to bottom.

Solution: GP 6 discusses the importance of staff training. However, not all staff, and certainly not the general public, know to avoid treated areas. In dealing with both staff and visitors, physical blockades and warnings enforce the message. Blocking previous access points with boulders, logs or ribbon, and possibly signs, would have eliminated a large and growing sediment delivery problem on Bubba's run.

Example 2: A large, disturbed area has been treated/revegetated next to a mountain bike trail. The Cross Country World Cup is to be held in a week and a large number of participants are in town to practice. The bike rally staff checks the course and requests that the maintenance crew fence off the treated area. However, the crew gets sidetracked on another project and believes they still have 5 days until the race. When the lifts open for practice runs, the bikers, seeing an open area with a pine needle cover, use that area for warm ups and as a short cut to the lift. By the time the fencing is put in place, the entire area, loose in the first place, is completely destroyed.

Solution: When the soil-vegetation treatment was completed, fencing should have been put in place, thus eliminating confusion. Further, signs would be put in place along the edge of the project explaining that this is a sensitive area and should not be traveled on.

Additional suggestions: Where all other restoration elements are in place, post-treatment disturbance is often the one factor that causes project failure. Early planning for how to avoid disturbance, pays off.

Section Three: Monitoring, Assessment, Follow-up and Information Sharing

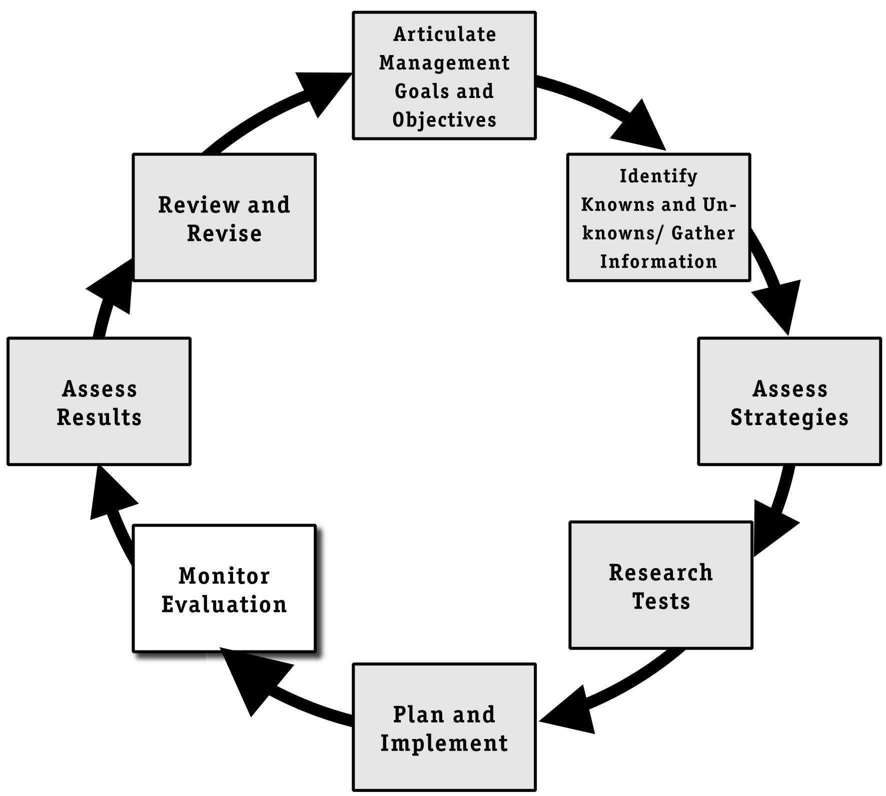
***Section Overview:** This section describes practices that monitor the effectiveness of site treatments. Monitoring or assessment informs the project proponents, regulators and other stakeholders, how the project is performing. Monitoring can also suggest where additional treatment may be required before small problems become large. This information can directly help improve the design of future projects.*

GUIDING PRINCIPLE 13: PERFORMANCE MONITORING

Goal: To assess project performance in a quantifiable manner against project success criteria and to gather information for a number of subsequent uses, as described in Guiding Principles 14, 15, and 16.

Description: There are three main types of monitoring:

- Compliance monitoring (meeting regulatory, especially water quality standards)
- Implementation monitoring (was the project implemented as planned. This type of monitoring is discussed in GP 7)
- Performance monitoring (how the project is *functioning* or *performing*)



It is this third type of monitoring that we are discussing here.

Monitoring should gather *useful* and *usable* information. Information or data should be linked to success criteria and should be quantifiable to the greatest extent possible. When quantified, information is less prone to interpretation and thus argument. Visual interpretation is generally not very reliable. The monitoring helps the reviewer understand, not only if success criteria are met, but also how the project is functioning.

Monitoring may include any or all of the following, depending on project needs and requirements:

- Soil nutrients analysis
- Soil density (penetrometer measurement)
- Plant and mulch cover (cover point)
- Visible erosion
- Weedy species
- Bare areas
- Drainage and/or hillslope hydrology functions

Performance monitoring will determine whether success criteria are met and trigger management responses (see GP 3) when they are not met.

Example: A project is constructed on the Lower Left Out run of Inner Mongolia. Success criteria list, among other things, a requirement that no bare areas of greater that 15 square yards shall exist in the treatment area and that, of the 300 seedlings planted, a survival rate of 50% would be expected. Upon inspection, a large bare area was noticed as a result of a small surface slump. Further, in the nearby area planted with seedlings, only 40% had survived, some of which had been in the surface slump area. The erosion control director who had been tasked with inspection, noted the problems.

Solution: The success criteria included management responses to both of these issues. The bare area management response was to re-treat the area. Since only a slight amount of movement occurred, most of the soil amendment was in place. Soil was moved back into place by hand, some reseeding was done, followed by mulching and irrigation. Since only 120 seedlings survived the winter and a plant census showed that two particular species had the best survival rates (85 and 70%), 75 individuals of those two species were planted and irrigated. When the USFS staff inspection took place 3 weeks later, the area was already showing a robust cover of young green shoots in the re-treatment area and the newly planted seedlings were showing good growth and new buds as well.

The results of this process eliminated the need for the USFS inspection staff to take any sort of action since the responsibility and initiative for action had been taken by ski area staff. Inspection was positive and non-confrontational.

Technical Note 7: Monitoring: Soil nutrient sampling; Cone penetrometer sampling; Cover point monitoring; Soil site characteristics/existing conditions assessment

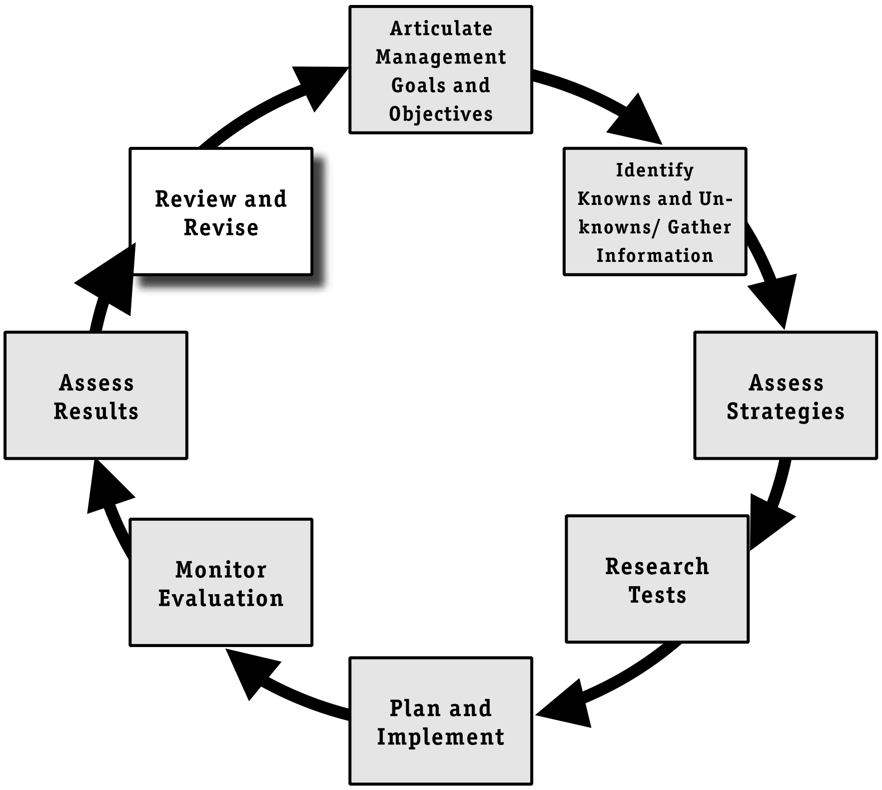
Additional suggestions: Latitude exists to develop and suggest monitoring protocols and procedures that may be less expensive and/or more accurate in determining project function. For instance, cone penetrometer readings may provide more information about site erosion potential than cover point monitoring. Work is needed to determine which monitoring methods are most useful and cost effective.

GUIDING PRINCIPLE 14: FOLLOW-UP TREATMENT

Goals: 1) to address problem areas that fail to meet success criteria so that they can be brought up to acceptable levels; and 2) to input additional resources (water, seed, fertilizer, etc.) that may be needed in subsequent seasons to assure the success of certain treatments.

Description: Small follow-up treatments can reverse problem trends quickly and cost effectively. If left alone, small problems can become a large and expensive problem to repair.

Example: A newly treated area is inspected the following season. A small rill has carried water from above the run and at one point, has resulted in a small rotational failure (mini-landslide). The inspector follows the rill upslope and finds that a waterbar has filled with sediment and breached. The waterbar has a slight level spot, which accumulated sediment, thus causing the breach. The waterbar was re-cut, the rill was hand tilled and re-seeded and the rotational failure was rebuilt, and reseeded. All were irrigated.



Solution: The solution, described in the 'Example' section, while somewhat time consuming, dealt with a relatively small problem. Left untreated, this trend would have resulted in a large gully forming which would have also run across a key service road, requiring reengineering of the road as well as partial rebuilding of the run. A relatively small amount of work precluded a great deal of work later.

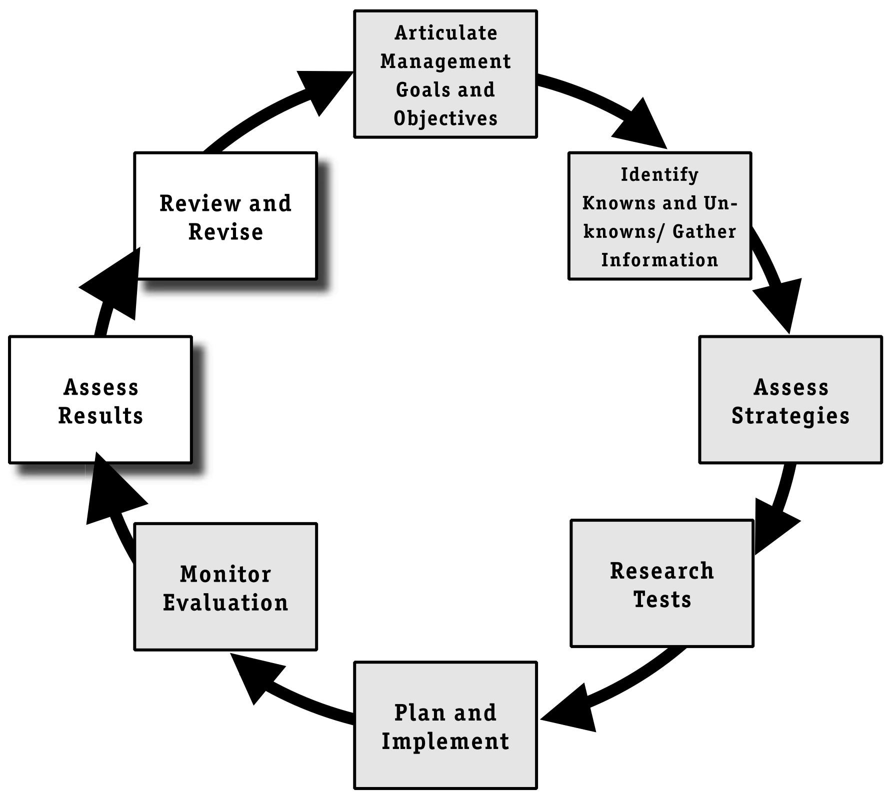
Additional suggestions: Follow-up treatment includes standard post-project treatments such as supplemental irrigation and fertilization. Most projects are more cost effective where follow-up treatment such as these are minimized and/or employed for as short a time as possible. If an area needs ongoing irrigation or fertilization to maintain 'success', once expensive follow-up treatments are ended, the site is likely to revert to low plant cover and high run-off potential.

GUIDING PRINCIPLE 15: FUTURE PROJECT IMPROVEMENT

Goal: To assess information from existing projects to improve future projects.

Description: When gathering information from existing projects (see GP 7 & 13), that information, if processed and assessed properly, can enhance future projects. This is especially true if experimental elements have been included. Treatments that worked well can be replicated and modified. Treatments that haven't worked as expected can be eliminated or more radically adjusted for future projects.

Example: Hydroseeding and fertilization with ammonium phosphate or ammonium nitrate (16-20-0) had been used in the Lake Tahoe Basin for over twenty years. No goals, success criteria or monitoring was done on those projects. Current monitoring is showing that most projects on drastically disturbed slopes did not limit erosion to acceptable levels.



Solution: Monitoring linked to appropriate success criteria would have allowed project inspectors to realize that hydroseed and chemical fertilizer treatment weren't producing desired plant cover or sediment source control. We would be much further along in the process of ensuring sediment source control in the Tahoe Basin and other alpine environments.

Additional suggestions: There is no existing formula to take monitoring data and create a direct improvement mechanism. It is most useful to try to eliminate what doesn't work and improve on what does.

Guiding Principle 16: Information Sharing

Goal: To share useful project information so that other project planners, implementers, and assessment personnel can improve their practices.

Description: This step assumes that environmental improvement should be universally beneficial and not limited by proprietary processes. Where information can be shared effectively, the information benefits the environment and others doing similar work. This commitment to share information brought the CAREC team together.

Information distribution can take many forms such as web-based distribution, professional society or group meetings, newsletters and so on. If tracked efficiently, information sharing improves the state-of-the-art in sediment source control, thus benefiting users environmentally and economically.

Example: A ski area employee has just been appointed head of erosion control. Reading a trade publication, she begins to assume that hydroseeding is the most powerful process for erosion control on the planet. A magazine article shows two people and a car, all had been hydroseeded, and were completely covered in grass. She contracts with a local hydroseed specialist to seed an eroding run for the sum of $2000/acre, a relatively reasonable sum. The following season, nothing is growing and the new manager must defend her job. Photos from the magazine article are not convincing!

Solution: The manager goes onto the web to a newly developed CAREC web site that lists local results of a number of erosion control field test applications. She sees that in high alpine situations on her soils, hydroseeding produced inconsistent results. However, a more expensive 'full soil and vegetation restoration treatment' had been shown to completely eliminate runoff and thus erosion, for the 3 monitoring seasons to date. She quickly calculated how many times she would have to hydroseed to equal the cost of the soil treatment. She reasoned that four hydroseed treatments would roughly equal one full soil treatment, which she implemented. This information assured her of success and since the following season the results were irrefutable, solidified her job as well.

Additional suggestions: Information sharing is challenging since most practitioners are extremely busy getting their normal work accomplished. However, when information sharing is efficient, work will be more effective since practitioners will not have to treat the same site multiple times.

The California Alpine Resort Environmental Cooperative

Sediment Source Control Handbook Part II

Technical Notes

Preliminary Version – APRIL 2005

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TABLE OF CONTENTS

INTRODUCTION TO TECHNICAL NOTES

The California Alpine Resort Environmental Cooperative (CAREC) came together in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field plots, with various approaches to control sediment on site and thus reduce erosion. As part of the Sediment Source Control Handbook, the group wanted Technical Notes that would provide detailed explanations for land managers to select appropriate treatments. Ultimately, the idea is that there will be detailed Technical Notes that provide more in-depth information for every Guiding Principle. This April 2005 preliminary version of the Technical Notes will be modified repeatedly over the next three years in consultation with the CAREC team, to make them as useful as possible to ski area land managers.

A great deal remains to be learned about the control of erosion and the establishment of a sustainable plant-soil system that is capable of controlling erosion and sustaining a robust plant community. Many of the so-called BMP's or "Best Management Practices" in use today have either been inadequately tested and researched or are not correctly implemented (improper installation or lack of site specificity.) This situation poses both a challenge and set of opportunities to land managers and regulatory agencies alike. These Technical Notes are intended to describe key treatment approaches as a starting point towards developing better practices, procedures, materials and monitoring protocols. For references cited please see the Reference List in the Literature Review (Handbook Part III).

CALIFORNIA ALPINE RESORT ENVIRONMENTAL COOPERATIVE
SEDIMENT SOURCE CONTROL HANDBOOK PART II

DRAFT TECHNICAL NOTE 1

ASSESSING SITE CONDITIONS

Description

To assess site conditions, information is gathered from a project area to understand the nature and character of the site. This information is gathered before a project is initiated, during implementation, and after a project is completed. The information can be used for project planning and project tracking and monitoring.

Site assessment should gather as much information as needed to adequately understand the site. Types of information typically gathered include: site physical characteristics such as slope angle and aspect; solar exposure; soil type; soil density; surface cover; site location (lat-long - GPS coordinates); and directions to the site. Site biological information often includes: soil type; nutrient levels; soil texture; vegetative community; soil moisture; etc. A standard CAREC form is included in Technical Note 2: Site Assessment Baseline Information.

Adequate site assessment lays the groundwork for deciding what sorts of treatments and materials are needed to achieve project goals. For instance, if a planner does not know the nutrient level in the nearby soil and in the disturbed soil, it will be impossible to accurately specify the amount of material needed to replenish nutrient levels in the treatment area. Thus there will be a tendency to over or under estimate amounts of fertilizers or soil organic amendments. When the appropriate information is collected and USED, whether and why a project is or isn't functioning as intended, can be better understood.

Appropriate uses, applications

Site assessment is important on every project. Different projects require different levels of site assessment from basic for small projects to more in-depth assessment for complex, large projects.

Alternatives

Table 1.1: Types of Soil Physical Assessment

Type	**Analysis**
Site Physical Assessment	Useful for getting a physical understanding of the site and exact location. This information includes such things as slope, aspect, soil type, location and so on.
Soil Nutrients	Critical to understand how much and what types of amendments may be needed.
Soil Density	Important key to understand the soils ability to infiltrate and store water. This assessment will suggest what type and how much soil physical preparation will need to take place.
Solar Input	The amount of sun that reaches a site each day influences vegetation and evapo-transpiration. Solar input can be measured by a number of devices. A Solar Pathfinder (*www.solarpathfinder.com*) is used to site houses for either active or passive solar systems. For our purposes, the higher the solar input, generally, the higher the evapo-transpiration from a site and thus the less available water in the soil.
Soil Moisture	Soil moisture data, when compared to other similar sites, will help the planner to understand whether this soil is able to hold adequate water or whether additional irrigation, organic matter or mulching will be needed to reach the required moisture levels in the soil.
Other	There are a great many assessment protocols that may be used. The main criteria should be the NEED for the information and the usefulness of that information to the planning, implementation and monitoring or tracking process

Table 1.2: Types of Monitoring/Assessment

Type of assessment	Analysis
Baseline or Pre-assessment	Used to gain an understanding of existing conditions, to specify the appropriate amount of materials or treatment to use and as a reference for follow-up monitoring. See Technical Note 2.
Implementation Monitoring	Used to assess whether actual application matches specifications or plans. This should be done with ski area crew or with outside contractor. This type of monitoring attempts to answer the question “Are we getting what we’re paying for?”
Performance Assessment or Monitoring	This type of assessment, also called ‘functional monitoring’ (is it functioning correctly?) is used over time following project completion and should be done for at least 3 or more seasons. Specific parameters monitored will depend upon the project scope, purpose, requirements and budget.
Water Quality Monitoring	Water quality monitoring is not covered in this document. Water quality monitoring may, or may not, provide a direct link to erosion control project performance.

CALIFORNIA ALPINE RESORT ENVIRONMENTAL COOPERATIVE
SEDIMENT SOURCE CONTROL HANDBOOK PART II

DRAFT TECHNICAL NOTE 2
GATHERING BASELINE INFORMATION

Description

Site assessment-baseline information has two main purposes: 1) to collect information that will help the project planner gain a more complete understanding of site parameters (see Technical Note 1: Assessing Site Conditions); and 2) create a standardized input format for database information gathering in order to more easily track project info, especially baseline info (what the site was like before treatment). The purpose is to use the information to better understand project outcomes.

For example, if we apply a soil-revegetation treatment, it's difficult to interpret that outcome without knowing what that site was like prior to treatment. When we revisit a site a year or more following treatment, it is difficult to remember what was done. This form lays the foundation for data interpretation.

Appropriate Uses, Applications

All project sites should have some base level of project site information collected. This information will be the basis of as-built documents as well.

Form Description

The following fields are suggested as a standard, basic format. Some projects will gather additional information. This form is designed to be simple to use and can be done in a very short period of time. Complete information should take less than one half hour to complete, with additional data gathering such as soil sampling and vegetation/cover assessment taking longer to complete.

SITE ASSESSMENT DATA SHEET

Company, name, title of person doing site assessment:

Project name:

Date:

Location description:

Location coordinates (Lat-long/GPS points):

Purpose of project:

Landscape information:

Slope:

Aspect:

Elevation:

Soil parent material:

Landscape position (upland, meadow or flat, riparian, wetland):

Landscape shape: (concave, convex, undulating, etc.)

Level of current disturbance: (none, low, moderate, high [construction projects would likely rate as high])

Photo points taken? Y__ N__

Photo point locations (GPS Coordinates and compass direction)

GPS-lat long ____________ Compass direction (degrees)_______________

Project map or drawing attached?

Cover (plant and mulch) assessed? Y___ N____

Type of assessment (Visual estimate, measured)

Cover %: Plant _____ Mulch ______

Number of soil samples taken?

Soil sample location map attached?

Soil density measured (cone penetrometer, other):

Overall site condition prior to construction or treatment (disturbed, native, well or poorly vegetated):

Type of project to be constructed:

Construction contractor or implementer:

Erosion control treatment foreman and personnel:

Dates erosion control implemented:

General description of erosion control measures implemented:

As-builts of erosion control attached?

CALIFORNIA ALPINE RESORT ENVIRONMENTAL COOPERATIVE
Sediment Source Control Handbook Part II

Draft Technical Note 3
Soil Physical Preparation

Description

Soil physical preparation consists of breaking up or loosening the soil to increase water infiltration, root penetration, aeration and nutrient movement. Physical preparation is generally done on highly compacted or otherwise dense soils.

Drastically disturbed sites, such as road cuts, ski runs and construction sites, often have high levels of compaction and high-density material, usually a result of construction activities. Road cuts in the Sierra Nevada for example, usually consist of dense subsoil or parent material. Compaction and high bulk density result in negative impacts on soil, plant growth and ultimately erosion from that site. Soil physical treatment is used to de-compact the soil to allow increased infiltration, root penetration, gas exchange and aeration for both plants and microbes.

Opinions vary as to the recommended depth for soil loosening. Twelve inches is currently the standard, representing a trade-off between ecological/hydrologic benefits and costs. Given a compacted soil of 20% pore space, calculations suggest that for each additional inch of tilling, the soil will be able to hold an additional 0.31 gallons per square foot. So the difference between 6 and 12 inches over an acre would be 81,675 gallons of water potentially infiltrating into the soil and/or stored in the soil as water for plant growth. Thus, the two main benefits of soil preparation, beyond the effect on plant growth, are increase in infiltration and the associated decrease in runoff as well as the increase in the amount of water stored.

Soil physical treatment includes tilling, ripping, turning soil over or the use of infiltration tines to open and loosen dense soils without turning them over. The latter technique is used on a steep and/or unstable slope where massive disruption of the soil 'strength' may result in a mass-type of soil movement.

Physical treatments are often combined with applications of soil amendments such as compost or aged wood chips in order to incorporate materials to a specific depth as tilling or ripping is done. Table 3.1 lists a number of treatment types.

Appropriate Uses, Applications

Soil physical treatment is used wherever soil density is high enough to limit plant growth and infiltration. The best way to determine whether the soil is artificially dense is to measure density on a native or highly functional site as a reference. No standards have been set relative to what is 'acceptable'. However, if density is 20 or more percent higher than the native site, it is advisable to apply some sort of soil physical treatment. As more information is gathered from ski areas regarding this critical issue, better guidelines will be developed.

Alternatives

Table 3.1: Soil Physical Treatments

Alternative	**Analysis**
Machine Tilling	Machine tilling includes soil loosening by backhoe or hoe-equipped excavator. This type of tilling completely mixes the soil and any amendments that are placed prior to tilling, allowing for a more consistent break up of dense soil. The potential drawbacks include destabilizing very steep slopes. In some cases, access is difficult for backhoes and excavators. In cases of very steep slopes, tilling can be done with a reach forklift or other mechanical means. However, when steep slopes are tilled, it is essential to establish plants immediately in order to stabilize the slope with plant roots. Tilling applications can be extremely cost effective if access is good.
Rototilling	Rototilling involves turning over the soil using a rotary tine attachment on either a hand operated machine or a tractor. Typically, in mountainous soils, rototilling is of limited usefulness due to the rocky nature of the soils. Rototillers can penetrate up to 4-6 inches, depending on the nature of the soil.
Ripping	Ripping uses ripper shanks to penetrate, decompact, and loosen the soil. Ripping is usually faster than tilling but is not always as complete for mixing. Since ripping is done by tractor-mounted attachments, slope angle can be a limiting factor for where ripping can take place. Winches can be used to extend the areas where ripping can take place.
Hand Tilling	Hand tilling is used where machines are not available or cannot reach. Hand tilling is limited by how deep hand tools can go and the enthusiasm of the hand labor crew. Typically, six inches is the limitation of hand tilling depth.
Auguring/Drilling	Auguring and drilling is utilized on very steep slopes where other methods of soil loosening would tend to destabilize the slope. Drilling is done such that the native stability of the soil is maintained. Holes are drilled on 6, 12 or other centers to ensure that a general level of stability is maintained. Drilling allows soil amendments, water, and plant roots to penetrate down into channels, thus encouraging some level of plant growth and infiltration/water storage. In many cases, drilled areas need to be irrigated for one or two seasons. Irrigation MUST be done infrequently and deeply so that water can penetrate down into the channels, thus encouraging roots to follow the water. Shallow irrigation will result in shallow roots, thus defeating the purpose of drilling.

KNOWN OR MEASURED OUTCOMES

- Increase in infiltration and thus runoff. In some cases, soil treatment has produced measured infiltration rates of over five inches (5”) per hour.
- Increase in water holding capacity and thus reduction in need for irrigation
- Increase in organic matter content and nutrient cycling, if combined with organic matter application.
- Increase in oxygen exchange through the soil, which is a key element of both microbial activity and disease suppression.

SUGGESTED SUCCESS CRITERIA

Low soil density to specified depth. i.e. resistance to force no greater than 200 psi to a depth of 12 inches using a cone penetrometer.

MEASUREMENT METHODS FOR SUCCESS

Cone penetrometer, infiltration measurement device (many available)

MANAGEMENT RESPONSE TO LACK OF SUCCESS

Re-treat to adequate depth

SUGGESTIONS FOR FURTHER ACTIONS OR INFORMATION NEEDED

- We need more information on a range of infiltration rates given specific types of treatment and different types of soil. In the next few years, CAREC will be using rainfall and runoff simulations to gather more of this information.
- More information on the respiration response of various types of treatment needs to be developed.

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DRAFT TECHNICAL NOTE 4
FERTILIZERS

Description

A fertilizer is any material that adds nutrients to the soil usually with the intention of supporting or increasing plant growth. Fertilizers range from mineral fertilizers such as ammonium nitrate (NH_4-NO_3), or other mineral nitrogen forms, to a number of organically derived materials. The difference between fertilizers and soil amendments is sometimes indistinct, in that some soil amendments have a nutrient content and thus act as fertilizers (delivering nutrients to the soil), and some fertilizers actually change the soil physical make up and thus act as soil amendments. In fact, most 'soil amendments' will provide some nutrient input and thus fill two functions.

Mineral fertilizers, especially those known as 'nitrogen' fertilizers, are largely synthesized from atmospheric nitrogen. Mineral fertilizers contain most of their nutrient load in an available form. This is important to know in that available minerals, especially N, tend to be highly mobile and thus are prone to leaching and do not tend to persist. Therefore, if mineral fertilizers are used, they must be applied frequently to be effective. An exception to this rule is the case of the slow-release, usually coated fertilizers. This type of fertilizer is a class of mineral fertilizers that are coated with a polymer or other material so that the release rate can be controlled.

Organic fertilizers derive some, or all, of their nutrient load from organic sources. There is some discussion of what 'organic' means. Chemically speaking, an organic compound is anything that contains carbon molecules. Thus, at least one fertilizer that claims to be organic is derived from lignite, a coal-based product and is then mixed with urea for its nitrogen source. At the other end of the organic spectrum there are fertilizers that have undergone the rigorous scrutiny of organic certification programs such as CCOF *www.ccof.org* or Oregon Tilth *http://www.tilth.org/site/*. These products are derived from clean, non-GMO (genetically modified organisms) organic sources and must be free from specific chemical residue. Between these two extremes exist the most common organic fertilizers such as manures, various 'compost' materials and others.

Not all organic fertilizers act the same or perform with the same nutrient release rate. It is important to understand as much as possible about the particular material you are using so that it will meet project objectives. For instance, if you were applying a soil-revegetation treatment in the fall, and used a mineral, highly mobile fertilizer, that fertilizer would likely be gone in the late spring when most plant growth occurs. In this case, it would be better to apply that fertilizer in the spring when plants begin to grow and can access the fertilizer.

Appropriate Uses, Applications

Given the range of fertilizer types available, we list several web sites where information has been posted.

Use of a particular fertilizer should be linked to the need and the release rate of that fertilizer. If rapid nutrient release is desired, mineral fertilizers should be used. If a slightly slower application is needed, an organic or coated mineral fertilizer may be more appropriate. In other words, plant and soil needs and fertilizer should be matched. Over or under application or application of improper material is likely to be inefficient both economically and environmentally.

ALTERNATIVES

Table 4.1: Fertilizer Information Resources

Alternative	**Analysis**
http://www.fertilizer.org/ifa/	International Fertilizer Industry Association
www.calfertilizer.org/	California Fertilizer Industry Association
http://www.ext.vt.edu/departments/envirohort/factsheets2/fertilizer/jan89pr6.htm	University of Vermont Extension; good explanation of types of organic fertilizers
Anrcatalog.ucdavis.edu/pdf/7248.pdf	UC Davis publication about organic fertilizers for crops. Good general information

KNOWN OR MEASURED OUTCOMES

The outcome of fertilizer use should be adequate plant growth and little soil nutrient loss. Nutrient loss is difficult to measure. Adequate plant growth may be subjective, but if success criteria are developed for plant cover or density, those criteria can address whether the plant growth is 'adequate'.

MEASUREMENT METHODS

Soil tests are used to determine the amount of nutrients that are present in a particular soil. Take soil samples in adjacent native or undisturbed areas and compare that to the treatment area. Soil sample interpretation requires skill and experience, especially in the project area. Soil labs typically interpret results from an agricultural perspective, which can be misleading. Agricultural systems require one or more applications per season whereas revegetation projects in ski resorts typically utilize one-time applications, though some resorts have developed follow-up programs.

MANAGEMENT RESPONSE TO LACK OF SUCCESS

Additional applications may be appropriate. However, usually lack of success may be due to an improper matching of the plant-soil need to the fertilizer. A useful management response may be to determine the nutrient level of the soil and match that to the fertilizer.

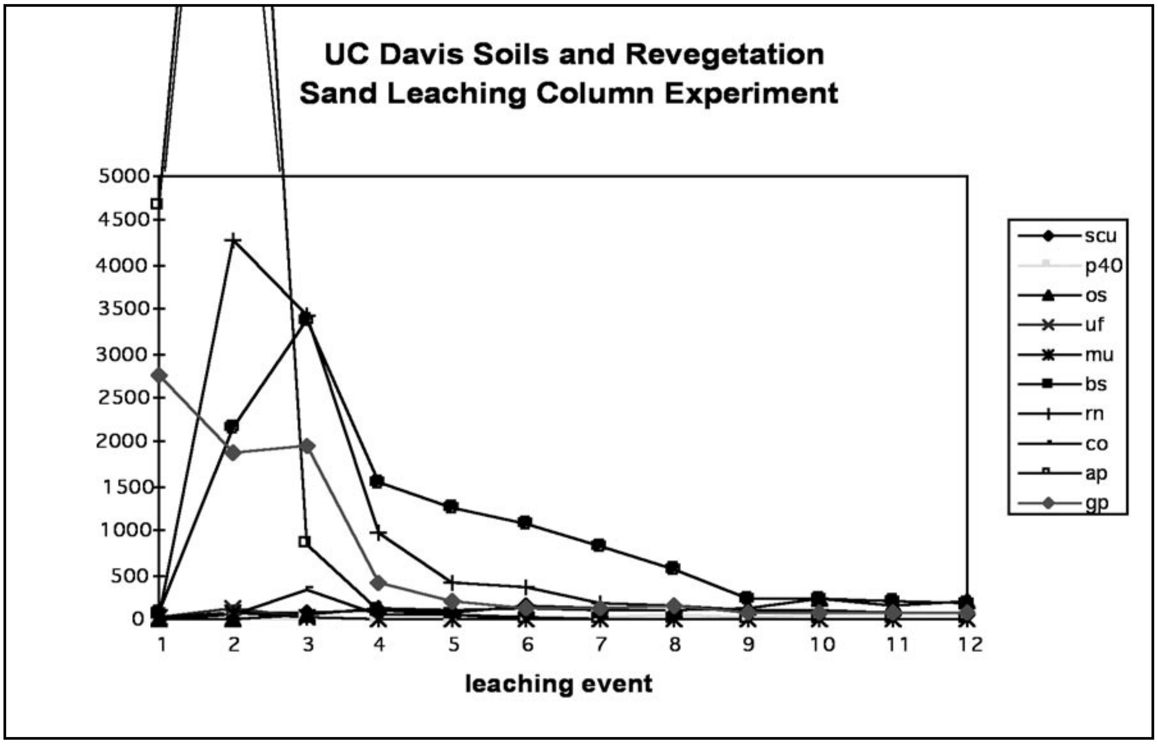

Figure 4.1: Leaching data for a number of mineral and organic fertilizers. The Y axis represents leaching events (water leached through a sand column containing one form of N-containing fertilizers or soil amendments). The X axis represents the amount of N leached from the sand column. Some fertilizers release most of their nitrogen in 3 leaching events whereas others deliver N over a much longer period of time. This information suggests that release rate must be matched with need. Further, some fertilizers, such as 'ap' (ammonium phosphate) may present a runoff and pollution threat if not absorbed by plants immediately. From Claassen and Hogan 1998.

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DRAFT TECHNICAL NOTE 5
SOIL AMENDMENTS

Description

Soil amendments describe any number of materials that are used to enhance soil physical or biological properties, such as water retention, permeability, water infiltration, drainage, aeration and structure. Soil amendments may consist of organic fertilizers (covered in the 'fertilizer' technical note), compost, tilled-in wood chips, mycorrhizal inoculum, or any number of other materials that are used to improve some element of the soil. Many soil amendments also contain nutrients and thus may be considered 'fertilizers', playing dual roles in soil treatment.

Appropriate Uses, Applications

Soil amendments are widely used and recommended for any number of situations where soil has been disturbed. Often, soil amendments are used without adequate understanding of exactly what is missing in the soil or without proper understanding of the potential and limitations of the amendment. In order to specify and apply the appropriate amendments, soil and plant conditions should be assessed (See Technical Notes 1 and 2) and the need for a particular amendment determined.

Perhaps the most widely useful soil amendment is compost[1]. Typically, in ski run construction or other 'drastic' disturbance, most of the organic topsoil layer is buried or removed. Once it is diminished or removed, the physical and biological functions needed to support the soil-plant system are severely impacted. In order to restore that these functions for the long term, organic matter will usually need to be added. In many cases, organic fertilizers or other amendments such as mycorrhizae are added with the belief that those additions will effectively 'restore' the system. However, if one assesses the amount of nutrients and organic matter that have been removed and compare that to the amount that is needed, it becomes clear that the addition of fertilizer or mycorrhizae is unlikely to replace the amount of nutrients or microbial activity needed for robust, sustainable erosion control.

For example, if 2000 pounds of an organic fertilizer with 6% nitrogen (N) was added to a site, that would provide the site with 120 pounds of actual N. The amount and form of N is likely to be inadequate to effectively recapitalize that site or support robust plant growth over an extended period of time. It has

[1]See additional websites on compost:
www.woodsend.org; *http://tmecc.org/sta/compost_attributes.html; http://www.epa.gov/epaoswer/non-hw/muncpl/comppubs.htm; http://attra.ncat.org/attra-pub/altsoilamend.html#soil*

been established that at least 1200 pounds of organically-bound N is needed for robust plant growth in the Tahoe Basin (Claassen and Hogan 2002). The type of N in organic fertilizers is generally of a much faster release rate and would likely be used up or leached from the system in 2-3 seasons.

On the other hand, composts tend to have a much lower N release rate albeit they vary widely. Figure 1 shows a graph derived from N release data from four types of compost. Two composts release a robust amount of N in a short period of time and then slowly release the remainder over time. However, two other types of compost actually lock up N, making it unavailable to plants for some period of time. While all of these 'composts' contain N, two would actually improve plant growth while two would diminish plant growth unless additional, more available N were added. Thus it is critical to understand what is in the soil in order to know what and how much to add to the soil.

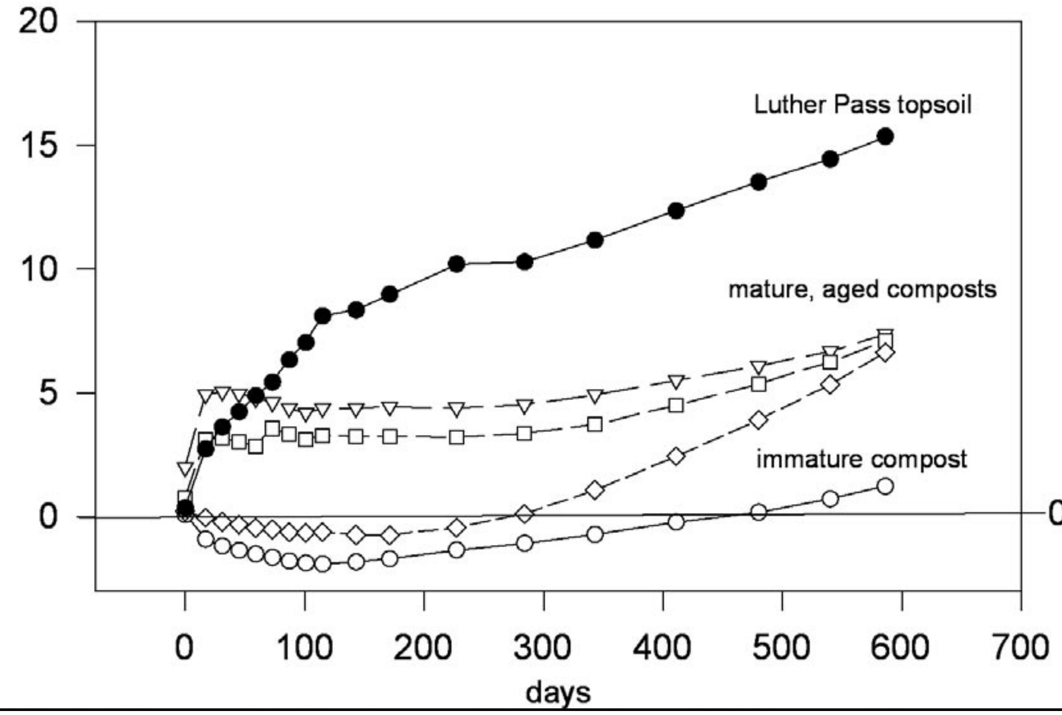

Figure 1 shows the differences in compost N release over time. This figure indicates the importance of matching the appropriate compost or soil amendment to a specific site condition. For instance, the immature compost actually removes or locks up nitrogen, and thus would tend to reduce or eliminate plant growth whereas the mature compost releases a much greater amount of N for plant growth (see Claassen and Hogan 1998).

ALTERNATIVES

Table 5.1: Alternative Soil Amendments

Alternative	Analysis
Compost	The term “compost” is used to describe a number of materials derived from the breakdown of organic matter. Unfortunately, there is little commonly accepted definition of compost material. To that end, the US Composting Council (USCC) has produced the following definition: Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and Processes to Further Reduce Pathogens (PFRP), as defined by the US EPA (Code of Federal Regulations Title 40, part 503, Appendix B, Section B) and stabilized to the point that it is beneficial to plant growth. Compost bears little physical resemblance to the raw material from which it originated. Compost is an organic matter source that has the unique ability to improve the chemical, physical and biological characteristics of soils or growing media. It contains plant nutrients but is typically not characterized as a fertilizer”(USCC, Field Guide to Compost Use). • Organic additions such as aged manure, aged wood chips, and a broad range of other materials, can be used as organic amendments. However, it is difficult to know what effect they will have on the soil without adequate testing. Some materials may not have the desired effect, others may have a greater effect than desired (for instance, excess N or P). The use of the above definition of compost will at least allow us to use the same term for a similar product. • One word of caution regarding using compost: some municipal composts are made from sewage sludge and even though this material is approved in some agricultural and forestry settings, this sludge derived material can contain a great deal of available N and potentially some heavy metals and pathogens. Before using ANY compost, it is important to know what it was made from and whether application of that material is approved by the local water quality control agency.
Organic Fertilizer	The term organic fertilizer covers a broad spectrum of materials from chicken manure to lignite/ammonium combinations. There are few standards to define an “organic” fertilizer. Materials approved for organic farming set a higher standard. Some organic fertilizers may contain a great deal of available nitrogen and phosphorus, thus creating a tendency toward leaching or nutrient runoff. Other fertilizers may contain residual toxins, introducing unwanted materials into the soil. For instance, one “organic” fertilizer has been banned by the Wyoming Department of Transportation because of the potential to import residual pathogens from the source - chicken manure. When choosing an organic fertilizer, it is useful to understand the relative release rate of the nitrogen and the amount of especially N and P needed, as indicated by soil tests.

Table 5.1 (cont): Alternative Soil Amendments

Alternative	Analysis
Mycorrizal Inoculant	Mycorrizal inoculant is intended to re-introduce a type of fungi into the soil that is an important element for plant growth in many types of plants. Mycorrizal inoculants are available from a number of producers or can be collected from native areas. The effectiveness of these amendments is the subject of a great deal of study and debate (see literature report).
Soil Conditioners	Soil conditioners are used to change or enhance a physical component of the soil. For a complete discussion of soil conditioners, see: *http://attra.ncat.org/attra-pub/altsoilamend.html#soil*
Seaweed Products	Seaweed products are added to a soil or compost pile to increase N and other minerals. Seaweed products may contain salts that can be harmful to plant growth.
Humates	Humates or "humic acids" are intended to mimic the "active" part of soil humus. The sheer volume of organic matter in moderately rich soils suggests that agronomically affordable applications of humates may not produce significant improvements. The top six inches of soil weigh approximately 1,000 tons per acre; each percent of organic matter, therefore, weighs ten tons. Even assuming that the organic matter in humate products actually is similar to that in soil, it requires two tons of humates per acre to increase soil organic matter by 0.1%.

Known or measured outcomes

Given the broad spectrum of soil amendments, it is difficult to suggest specific measured outcomes. However, anticipated outcomes for each soil amendment type should be listed by the supplier, and/or the planner. For instance, if the supplier suggests that mycorrhizae will increase plant growth, ask how much or by what measure. In that way, we can assess whether claims are actually borne out in high alpine conditions and whether the treatment is cost effective.

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DRAFT TECHNICAL NOTE 6
PLANT MATERIALS

Description

Plant materials include any live or potentially live materials such as seedlings, transplants, or seeds, used to enhance an erosion control or landscaping project. The selection of plant material should be considered relative to the specific function needed within an erosion control project. For instance, plants roots provide an important function in holding soil together and providing soil strength. Plants also provide mulch when they are mature enough to produce excess leaf material. Plant leaves provide cover over the soil, thus protecting soil from raindrop impact.

Functions associated with each individual plant type must match the need of the erosion control project. For instance, many grasses grow quickly and establish a plant community that can tie the soil together, produce surface mulch and help bootstrap the soil nutrient cycle. At the same time, some grasses are invasive or persistent while others die out in a few seasons. Seedlings of shrubs and trees provide greater root penetration and additional erosion control, but may not provide much protection for several years due to their slow growing habits.

The actual erosion control 'service' provided by each plant type should be carefully considered. The presence of grasses (or other plants) on a site does not necessarily assure that site of being erosion free. The ability to hold sediment is based on a number of elements including infiltration, mulch cover, adequate soil organic matter, and so on. Plants are one component of that system and are not the sole determinant of erosion. Plants should be selected in the context of the entire system within which they function.

Native vs non-native: Some ski areas, especially those on US Forest Service land, are required to use solely native species. Others may choose to do so or opt for adapted species. There are no clear-cut parameters for choosing native vs non-native in a strictly erosion control context. However, each type has its strengths and weaknesses. Historically, non-native grasses were used due to the belief that natives were more slow growing. However, recent experience has shown that some native grass species, such as Bromus, Elymus and others, grow as fast as most of the adapted species. It is also commonly believed that native plants can thrive on nutrient poor soils. This has been shown to be erroneous.

Native vs native: Another consideration when choosing a native species is whether it is genetically indigenous or simply the same species. For instance, *Elymus elymoides* (Bottlebrush Squirreltail) grows from the California coast to the upper elevations of the Sierra Nevada and across the Great Basin. However, the genetic makeup, and thus growth habits and preferences of the same species growing in different locations, vary broadly. If native species are used, it is suggested that local genotypes be selected. There is some concern that local gene pools may become ‘polluted’ or weakened by non-local genotypes. Beyond the genetic considerations, locally collected plant material will usually perform better than material from a different climate and altitude.

Weed free seed: Seed should be specified as weed free since even native seed, when field grown, can introduce weeds. Weeds, introduced in seed mixes or straw mulch, can become established and crowd out more useful species. Some weeds, such as Tall Whitetop (*Lepidium latifolium*) can be extremely invasive.

Pure Live Seed (PLS): The concept of pure live seed is extremely important in the ordering and application of seed to a project. PLS is the amount of seed that can actually be expected to grow within a batch of bulk seed. All seed should be tested within the past year. Tests will indicate how much of the material in the seed bag is actually seed (some material may be ‘fluff’ or ”chaff” or other material). Some of the seed itself may not be viable. Seed testing determines the amounts of non-seed and non-viable seed and is usually reported as ‘impurities’ and ‘viability’. So if 20% of a 50 pound bag of seed is made up of impurities and non-viable seed, then only 40 pounds of that bag contains seed that can be expected to grow. Therefore, if one needed to apply 40 pounds per acre, 50 pounds of bulk seed would be required. It is important to always order and specify seed as PLS. For instance, if a seed supplier had an old bag of seed in which only 10 percent was viable and you applied 100 pounds per acre, you would only be putting 10 pounds of actual live seed on that acre – a guaranteed poor plant response rate.

Appropriate Uses, Applications

Plant type, growth habits and aesthetic value should be matched to the project goals. For instance, if erosion control was the main goal, one may not choose seedlings as the first line of defense since seedlings usually do not develop significant root structure or canopy cover for a number of years. A great deal of work remains to be done on how a range of native shrub and tree species seeds can be used successfully in erosion control projects.

ALTERNATIVES

Table 6.1: General Assessment of Various Plant Types, Forms and Habits

Alternative	Analysis
Grasses	Quick growing, usually fiberous root structure. Grasses require moderate to high amounts of water. Some grasses are better as scavenging water than others (Elymus elymoides, for instance).
Forbs	Some are quick growing, add to aesthetic of a site; difficult to get native seed.
Shrubs	There are a broad range of shrubs available. Some research is required to determine habits, requirements, etc. Shrub seedlings usually require some supplemental irrigation in the first season. Possibly the most effective means of choosing the proper shrubs is to contact the local nursery, especially if they deal with native plants.
Trees	Very slow growing - of limited use in ski areas.
Seed vs seedlings	Seed is usually most appropriate for grass establishment. Shrubs and trees may be established more quickly by planting seedlings. However, seedlings (live plants) are much more expensive to install. More work needs to be done on the ability of many plants to grow from seed. Native plants demonstrate a range of response to direct seeding due to cause and effect relationships such as soil type, nutrient level, mulch depth, solar radiation %, and other factors that affect germination. Germination triggers are not always known, or when known– as with fire, may not always be available.

KNOWN OR MEASURED OUTCOMES

APPLICATION

Seed: seed should be very lightly raked into no more that 2x the diameter of the seed. Some seed prefers to lay on top of the soil. Particulars should be given by the seed supplier.

Seedlings: General procedures include soil preparation, adequate planting hole size, supplemental irrigation, mulching.

SUGGESTED SUCCESS CRITERIA

For grasses, a cover percent (e.g. 40% of treatment site covered within 2 years). For shrubs, a survival number (e.g. 50% of 300 shrub seedlings survived first 3 years with at least 4 different species represented at the 10%+ level.) Measures: Grasses: cover point (best), quadrats (ok) or ocular estimate (least accurate).

MANAGEMENT RESPONSE TO LACK OF SUCCESS

For grasses, re-treat site and re-seed.

For shrubs, replant 2 or 3 new shrubs to every 1 dead.

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Draft Technical Note 7
Monitoring

Description

Monitoring describes the observation or assessment of the outcome of an erosion control project. To evaluate whether the project is performing the way we intended and whether we have gotten adequate value, monitoring is essential. Types of monitoring include:

1) Baseline monitoring - pre-project assessment;

2) Implementation monitoring - assessment during or just after project completion to determine whether the project was constructed properly; and

3) Performance monitoring - assessment of the outcome of a project .

The types of monitoring described below, while not exhaustive, can be used in all three types of monitoring.

Appropriate Uses, Applications

Specific types of monitoring for erosion control projects are listed in the table below. Monitoring activity measures must directly link to project goals. For instance, measuring plant cover will not directly measure erosion reduction. Measuring soil density will not directly measure the aesthetic values of the project.

ALTERNATIVES

Table 7.1: Types of monitoring for erosion control projects

Alternative	**Analysis**
Photo point Monitoring	A simple, yet important component of any monitoring system. It is the least defensible type of monitoring however. Photo points are ideally mapped or linked to a geography point so that multiple photos can be taken over the seasons from the exact same location, or locations, so that visual observations can be made. Ideally, photos are most comparable if taken during the same time of day and similar lighting conditions. If project budgets are limited, photo monitoring should be minimized. If photo monitoring is done once yearly, it should be done on approximately the same day of the year or as closely as possible. Otherwise, for example, if one photo is taken in June when plants are green and vigorous and another is taken either in April before plants are growing or in October when plants have senesced, photos will be very misleading for project interpretation.
Cover Monitoring	There are several types of cover monitoring – see Hogan 2003. Generally, the more intensive the monitoring, the more reliable the information but the more time consuming. Cover monitoring ranges from visual or ocular estimates, which are very unreliable, to cover point monitoring done to a specific confidence level. Cover monitoring typically assessed plant cover by species or at least plant type, and ground cover, including mulch, rocks, woody debris, etc.
Soil nutrient Monitoring	Soil nutrient monitoring is used to assess the amount of nutrients in a project site so that adequate nutrients and organic matter can be added back into the soil. Nutrient monitoring can also be used post project to determine whether adequate nutrients have been added. It is advisable to use the same lab for all samples. A great deal of nutrient data has been collected for the Tahoe-Truckee area that may be applicable to other areas of the Sierra.
Soil Density Monitoring	Soil density monitoring is used as an index of infiltration of water into the soil. In other words, the less dense the soil, generally the more 'air' and pore space exists. The more pore space, the higher rate of infiltration. The amount of runoff is directly related to the amount of infiltration and thus to sediment yield. Soil density monitoring is done using a cone penetromer. It is extremely easy and rapid and gives a great deal of information about how well and how deeply tilling has occurred.
Erosion Monitoring	Erosion monitoring is usually done visually and should take place during or just after a runoff event such as a rainstorm or snow melt. Erosion monitoring can produce a great deal of information about the source of runoff, the amount of runoff and so on. This type of real-time erosion monitoring is essential to gaining a full understanding of the erosion process in ski resorts and elsewhere.

KNOWN OR MEASURED OUTCOMES

SUGGESTED SUCCESS CRITERIA

Grasses (cover): increasing cover for first three seasons up to 40%, i.e.: year one - 10%; year two - 25%; year 3 - 40%.

Mulch (cover): year one - 98%; year two - 95%; year three - 90%.

Soil Nutrient Monitoring: soil organic matter within 20% of native or reference site for total nitrogen (TKN): at least 1500lbs/acre. This is an example only as each area needs to establish what the TKN is in adjacent robust native sites. See Claassen and Hogan, 2002 in Literature Review.

Soil Density: following treatment, penetration to 12 inches with no more that 250 psi (pounds per square inch) required.

MANAGEMENT RESPONSE TO LACK OF SUCCESS

Grasses: re-treat and/or re-seed

Mulch: re-apply mulch

Nutrients: re-apply appropriate nutrient or soil amendment

Density: re-till to appropriate depth

The California Alpine Resort Environmental Cooperative

Sediment Source Control Handbook Part III

Literature Review

Preliminary Version – APRIL 2005

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INTRODUCTION TO THE LITERATURE REVIEW

The California Alpine Resort Environmental Cooperative (CAREC) came together in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field plots, with various approaches to control sediment on site. In addressing an issue as large and complex as erosion control, CAREC wanted to determine what we know, what we don't know and what we need to learn. This is an essential element of the adaptive management cycle discussed in Part I: Guiding Principles. As part of the Sediment Source Control Handbook, CAREC requested a Literature Review that references appropriate information for planners, practitioners, monitoring personnel and scientists involved in upland sediment source control projects.

The ability to return disturbed sites such as ski slopes to a high level of effective soil-plant function requires knowledge and understanding of ecological, physical and operational processes. Too often, this information is not easily available when erosion control projects are planned and implemented. Actual field-level or field-relevant research or other literature tends to be difficult to find or simply non-existent in the case of high alpine areas. Much of the information available is written by manufacturers and suppliers – with their own marketing slant.

This Review attempts to collect as much relevant scientific information on erosion and restoration-related subjects as possible. It is intended to be a working document that will be added to over time as additional research becomes available. Information is cited on erosion control and restoration in the following sections:

- **Section One: Erosion – Key Concepts**
  Establishes a common understanding of what is meant by erosion;
- **Section Two: Variables that Influence Erosion Rates**
  Describes types of erosion and particular variables that affect erosion rates.
- **Section Three: Treatments for Sediment Source Control**
  Suggests issues to consider when applying different types of treatments in support of sediment source control objectives.

The Literature Review complements Parts I & II of the *CAREC Sediment Source Control Handbook (2005)*.

FRAMING THE ISSUE

DEFINITION(S) OF EROSION

The entire process commonly referred to as 'erosion' actually consists of two closely related processes: 1) erosion, or the 'detachment or breaking away of soil particles from a land surface by some erosive agent, most commonly water or wind; and 2) sedimentation or "subsequent transportation of the detached particles to another location" (Flanagan 2002). It is important to understand the nature of these two processes, since addressing them requires quite different techniques and approaches.

Typically, controlling erosion requires keeping soil particles attached to one another and to the soil matrix. Native soils usually do this through the 'aggregation' process (Kay and Angers 2002 -

see pg a-263 section 7.4.3). Soil aggregates are combinations of soil particles that are bound together. Typically this process is the result of physical and biological, especially microbial, processes (Horn and Baumgartl 2002). When soil is disturbed, aggregates tend to disaggregate and are more prone to erosion. Once soil particles begin to move, it is extremely difficult to capture fine silt and clay particles, which are typically responsible for a great deal of water quality pollution and degradation. Thus, the CAREC work and this literature review focuses on 'sediment source control' — keeping soil particles attached and at the same location.

AN INTRODUCTION TO EROSION

Erosion and sedimentation pose a serious problem throughout the world. Any land 'improvement' or development is almost always associated with the potential for accelerated erosion and associated water pollution. This is especially true in mountainous regions where steep slopes and relatively young and/or poorly developed soils create ideal conditions for accelerated erosion once an area is disturbed. In order to take meaningful action to reduce or control erosion to acceptable levels, and thus protect water quality, it is useful to develop an integrated, comprehensive understanding of what erosion is and what we currently know about controlling it.

Erosion is generally a 'systemic' or functional issue rather than a two-dimensional surface issue æ the product of an entire system of environmental interactions rather than simply the amount of plant cover on a site. When a system is 'healthy' or operating at a high level of functionality, erosion will be low as soil particles will stay connected to each other on site. When one or more components of the system have been disturbed, erosion – the disaggregation of soil particles – coupled with sedimentation – or movement of those particles – is likely to increase.

Background, or 'natural' erosion tends to take place in an equilibrium with other watershed elements such as infiltration, stream flow, stream bank stability, vegetative community and so on. When disturbance takes place, this equilibrium is disrupted, resulting not only in increased sediment movement, but in an increase in surface water flow, an increase in stream water volume and velocity, a decrease in steam bank stability and a decrease in watershed water storage (Selby 1993; Dudley and Stolton 2003). On a watershed basis, accelerated erosion and sedimentation results in removal of watershed 'capital', or the carbon rich soil organic matter that drives so many important processes within a watershed. Carbon provides energy that in turn drives ecosystem processes. Once this 'capital' is diminished, the ecosystem tends to function at a somewhat lower level.

While diminished functionality may be barely noticed at small scales, when large areas such as roads or ski runs are developed, watershed function can be severely disrupted. When this happens, input and output erosion 'variables' are no longer in balance and often result in a downward spiral of ecosystem 'damage' or negative impacts (Daily, Matson, and Vitousek 1997). By replacing components of the larger soil-plant processes such as soil organic matter, seed, mulch, infiltration and so on, erosion can be reduced and water quality can be protected.

Most of the currently accepted 'erosion control' practices, based on models such as the Universal Soil Loss Equation, focus largely on the 'C' or cover factor. Thus, emphasis has been placed on plants or 'revegetation' as the primary solution to erosion control on disturbed sites. However, processes need to be put back as a system rather than as single components. The Literature Review captures the best academic research done to date on treatments that address soil-plant processes to maintain soil particles in place on steep slopes.

EROSION OVERVIEW – FROM INTERNATIONAL UNION OF GEOLOGICAL SCIENCES

Erosion, the detachment of particles of soil and superficial sediments and rocks, occurs by hydrological (fluvial) processes of sheet erosion, rilling and gully erosion, and through mass wasting and the action of wind. Erosion, both fluvial and eolian (wind) is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands, the rate of soil and sediment erosion approaches that of denudation (the lowering of the Earth's surface by erosion processes). In many areas, however, the storage of eroded sediment on hill slopes of lower inclination, in bottomlands, and in lakes and reservoirs, leads to rates of stream sediment transport much lower than the rate of denudation.

When runoff occurs, less water enters the ground, thus reducing site productivity. Soil erosion also reduces the levels of the basic plant nutrients needed for crops, trees and other plants, and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use, and provides an important transporting medium for a wide range of chemical pollutants that are readily absorbed on sediment surfaces. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals and fish.

Significance: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. In the USA, soil has recently been eroded at about 17 times the rate at which it forms: about 90% of US cropland is currently losing soil above the sustainable rate. Soil erosion rates in Asia, Africa and South America are estimated to be about twice as high as in the USA. FAO estimates that 140 million ha of high quality soil, mostly in Africa and Asia, will be degraded by 2010, unless better methods of land management are adopted.

Human or Natural Cause: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (plowing, irrigation, grazing), forestry, construction, surface mining and urbanization. It is estimated that human activities have degraded some 15% (2000 million ha) of the earth's land surface between latitudes 72° N and 57° S. Slightly over half of this is a result of human-induced water erosion and about a third is due to wind erosion (both leading to loss of topsoil), with most of the balance being the result of chemical and physical deterioration.

SECTION ONE: EROSION – KEY CONCEPTS

SECTION OVERVIEW

This section describes several concepts essential to a full understanding of erosion and key terms used throughout the literature and practice of sediment source control. The section also includes general information about the state of erosion control knowledge, the extent of the erosion problem, and prediction capacity.

DRASTIC DISTURBANCE

'Drastic disturbance' defines areas where "…the native vegetation and animal communities have been removed and most of the topsoil is lost, altered, or buried. These drastically disturbed sites will not completely heal themselves within the lifetime of [a person] through normal secondary successional processes (Box 1978)." Drastically disturbed sites describe CAREC treatment areas, such as ski runs, road cuts and fills and building sites. These areas must be considered as functionally and biogeochemically distinct from the pre-disturbance (native) site condition and treatment must focus on restoring structure and function, especially in the soil, if long term or sustainable solutions to erosion are to be implemented (Kay and Angers 2002) (Torbert, Burger 1994 and 2000), (Bradshaw 1992) (Whitford and Elkins 1986). While some sites may be lightly disturbed and may subsequently support vegetation, drastically disturbed sites most often require soil amendments and tilling or loosening.

SEDIMENT SOURCE CONTROL

The process commonly called 'erosion' actually consists of both erosion and sedimentation (See Framing the Issue above). Whether we address erosion or sedimentation will dictate to a great extent, the overall cost and effectiveness of treatment as well. For instance, by focusing on erosion, we attempt to keep soil particles in place, an approach commonly referred to as 'sediment source control'. Dealing with sedimentation, on the other hand, commonly involves 'treatment' of sediment-laden water downstream or downslope from the sediment source.

An innovative program has begun within the Lake Tahoe Basin, where a consortium of entities, led by the California Tahoe Conservancy, have developed what are being termed "Preferred Design Guidelines" (California Tahoe Conservancy 2002). They suggest that in project planning and implementation, the following design criteria be considered in this order of importance:

1) Sediment source control;
2) Hydrologic design and function; and
3) Conveyance and treatment.

This approach assumes that keeping sediment on site and in place, is more effective (both from a cost and environmental standpoint) than attempting to capture and treat it downstream. This approach is the outcome of an understanding that the most cost effective method of reducing sediment is to ensure that it doesn't move in the first place.

A DOSE-RESPONSE (AGRONOMIC) VS 'CAPITALIZATION' (WILDLAND) APPROACH

It is useful to differentiate between agricultural and 'ecological' approaches to revegetation, erosion control and restoration. The two main approaches are:

1. Dose-Response - refers to a system in agriculture or landscaping, such as a field of corn or a backyard garden, where a specific amount of fertilizer is applied with a pre-defined output or response. These types of systems are designed for a continual dose (input) and response (output) for as long as the desired process is in place. Generally, this type of system is artificially imposed in an area and is not designed to be self-sustaining.
2. Wildland – refers to a one-time investment or re-capitalization of a disturbed site. The desired outcome of a wildland treatment is typically a no- or low-maintenance, self-sustaining site as continual input and maintenance is not practical or cost-effective. Adequate amounts of materials as well as physical manipulation must 'capitalize' or 'invest' the system with nutrients, organic matter, carbon or other needed elements.

A FUNCTIONAL APPROACH

The ability to develop and apply effective erosion control techniques and materials depends to a great degree upon understanding of the processes of erosion over time. If an erosion control practice is to be effective, it must directly address one or more of the processes involved in erosion for the long term. For many years, plant cover (revegetation) alone has been used as a measure of erosion control effectiveness. While plant growth can be forced, through the ongoing use of adequate water and nutrients, the literature summarized here strongly suggests that: 1) an erosion resistant landscape is the result of a robust and well-functioning soil-plant system; and 2) the effective control of erosion on disturbed sites depends to a large extent on re-creating and re-integrating ecosystem function.

Cummings (2003) suggests that when assessing restoration or site 'success' we look not primarily at structure (the makeup of the physical plant community) as much as essential functional elements such as nutrient cycling, infiltration (hydrologic function) and energy capture (plant growth/carbon storage) on those sites. This approach is gaining popularity since it is becoming more apparent that while a site may 'look' good, visual interpretation is prone to individual bias and that bias is largely dependent upon levels of training and experience, which varies widely between individuals. Further, simple visual observations cannot discern internal function such as infiltration or nutrient content of the soil and it is these two latter elements that drive so much of the erosion process.

STATE OF EROSION CONTROL KNOWLEDGE

There has been a great deal of information put forth over many years regarding erosion and its control. Unfortunately, some of this information is inadequate for planning and implementing erosion control projects. We suggest at least four reasons for this situation, based on Sutherland, 1998a, 1998b and Benoit/Hasty 1994:

1. Single variables: many if not most studies tend to look at one or two variables. Multivariate studies are difficult to implement and interpret. However, restoration in a drastically disturbed site includes a wide range of variables. Therefore, single variable studies may be misleading or difficult to understand in a multivariate environment.
2. Site specificity: studies and tests that are done somewhere else in different climates, soil types and types of disturbance may not be relevant to sites in the Sierra Nevada or the arid west.
3. Inadequate experimental design: a number of erosion control studies have not been adequately designed and therefore the information derived may not be robust or dependable. For instance, Sutherland, in a critical review of rolled erosion control product studies found that very few studies had the scientific rigor to be dependable (Sutherland 1998a and 1998b). An explanation for this lack of rigor, is that many erosion control studies have been conducted by product manufacturers or suppliers. The implementers did not set them up as scientific experiments with statistical accuracy. Further, most of these studies were not presented to peer-reviewed scientific journals, but rather were presented in trade journals.
4. Time: most studies are not tracked over a long enough time period. Even Sutherland has only suggested that studies be more rigorous but does not consider effectiveness over time. Time is a critical consideration when designing and assessing projects, especially where soil restoration is important (Richter and Markewitz 2001; Bloomfield, Handley and Bradshaw 1982).

EXTENT OF THE PROBLEM

How important or pervasive is erosion? One often hears the comment “But isn’t erosion a natural process?” Several sources were considered in attempting to answer this question. According to Gray and Sotir (1996), annual sediment yields for the US range up to at least 2 billion tons per year. Of the total amount eroded, about 1/4th to 1/3rd reaches the ocean with the rest being deposited in flood plains, river channels, lakes and reservoirs. They report that “siltation and nutrients (nitrogen and phosphorus) from erosion impair more miles of rives and streams than any other pollutant”.

Erosion rates range from a low of 15 tons/mile^2/year for natural or undisturbed areas to a high of 150,000 tons/mile^2/year for highway construction sites, or a maximum difference of 10,000 times (US EPA 1973). According to Scheidd (1967), roads may be associated with erosion rates 10-50 times above background. According to Wark and Keller (1963), “Exposure of soil during the construction period can result in sediment production equal to 10 times the rate from cultivated land, 200 times the rate from a grassland, and 2000 times that from forest land”.

The California State Division of Soil Conservation found that roadways in the South Lake Tahoe area were the source of 78% of the total sheet and road erosion. Further, they noted that: "Ski slopes that are established by clearing mountainsides have marred the landscape and created erosion problems at the Heavenly Valley ski area in South Lake Tahoe. Erosion and land scars are noticeable, even though considerable effort has been expended to establish vegetation on the sterile granitic soil" (Resources Agency 1969). Grismer and Hogan, in Tahoe specific research, found erosion rates on disturbed sites to be up to 530 times greater than similar native areas (Grismer and Hogan, in submission).

PREDICTING EROSION

The ability to predict erosion has been important in designing and justifying many erosion control projects in the past. Erosion prediction is usually based on one or more currently used models. Many of the current models address erosion as primarily a surface phenomena. However, commonly used models such as the Universal Soil Loss Equation (USLE) and other related modes (RUSLE, CREAMS, GLEAMS, WEPP etc.), have proven inadequate to effectively predict erosion in wildland settings. Therefore, these models may be misleading when used to quantify the impact of treatments such as plant cover, mulch treatment and so on.

While models are useful as ways to envision erosive processes, a number of researchers suggest that actual control of erosion is likely to be enhanced by focusing on physical processes in the soil and interactions between components than by focusing on model outputs (Bradshaw 1992; Torri and Borselli 2000; Whitford and Elkins 1986; and Wilkinson, Grunes and Sumner 2000). For instance, Agassi (1996) suggests that "the successful design of soil conservation programs will be more easily achieved by studying the relationship between rainfall characteristics, sealing of the soil surface, and the ensuing decrease of infiltration rate than by studying and modeling erosion processes, as is currently being done." In Section Three we address specific approaches to erosion based on ecological processes rather than model assumptions.

SECTION TWO: VARIABLES THAT INFLUENCE EROSION RATES

SECTION OVERVIEW

This section describes the types of erosion and the variables that define whether, and to what extent, erosion occurs on a given site. Each variable affects erosion rates. An excellent description of types of erosion, and erosion processes, is provided by Gray and Sotir (1996) in Biotechnical and Soil Bioengineering Slope Stabilization (pgs 19-30). When more than one variable is impacted in a disturbance event, erosion is likely to increase. Table 1 lists the various types of erosion, what they are caused by and what influences them.

Table 1: Erosional Processes – Their Causes and Influencing Variables

Process	Cause	Variables
Splash detachment	Rain drop impact	Amount, size of droplets
Sheer detachment	Surface flow	Amount of water
Freeze detachment	Water expansion upon freezing	Amount of water in soil, surface cover, air temperature, cloud cover
Transport	Water velocity	Amount and speed of water
Deposition	Slowing of water; filtering of water; exceeding waters capacity to suspend particles	Velocity change, filtration mechanism
Mass failure, rotational failure	Differential soil densities, sliding layer, differential pore pressure	Different infiltration levels (including oversaturation) of one layer relative to another

TYPES OF EROSION

Erosion is generally split into two categories: water and wind. A third type of erosion, which is also related to water is referred to as 'frozen water' or 'winter' erosion, which includes snow and snowmelt erosion and frozen soil or 'freeze-thaw' erosion (McCool 2002). However, additional types of erosion such as colluviation and mass failures are also important.

Water

Liquid water erosion is the most commonly cited, and possibly best understood, type of erosion. The linkage between this type of erosion and water quality is relatively obvious. Splash detachment, transport, sheet flow, rill and gully concepts are part of water erosion. A great deal of literature describes these processes such as Torri and Borselli (2000), Le Bissonnais and Singer (1993), Moore and Singer (1990), Wischmeier and Smith (1978) and many others.

Freeze Thaw

Soils subject to freeze/thaw conditions have different processes affecting erosion and runoff measurement. Edwards and Burney (1987) used a laboratory rainfall simulator to test three Prince Edward Island agricultural soils (varying in soil texture) for runoff, splash volume, and sediment loss under varying conditions of freeze/thaw, ground cover and potential for erosion.

Figure 1: Freeze-thaw erosion showing detached soil particles

With bare soil, freeze/thaw significantly increased sediment loss by about 90%. Using the same procedures, Edwards and Burney (1989) examined the effects of freeze/thaw frequency, winter rye cover, incorporated cereal residue, and subsoil compaction on runoff volume and sediment loss. Wooden soil boxes were subjected to: 1) simulated rain at the end of a 10-day freezing period, and 2) at the end of the 5th 24-hour freezing period of a 10-day alternating freeze-thaw cycle (freeze-thaw). Where the soil was continuously frozen for 10 days, there was 178% greater sediment loss and 160% greater runoff than with daily freeze/thaw over the same period, but there was no difference in sediment concentration. Incorporated cereal residue decreased sediment loss to 50% and runoff to 77% of that from bare soil, suggesting that mulch can significantly reduce erosion in freeze-thaw conditions. Winter rye cover decreased sediment loss to 73% of that from bare soil. Simulated soil compaction caused a 45% increase in sediment loss. The loam soil showed 16.5% greater loss of fine sediment fractions >0.075mm than the fine sandy loam which showed 23.4% greater loss than the sandy loam.

Frozen Water and Wind

Little research is available regarding the amounts and types of wind or frozen water erosion in the Sierra Nevada or other resort regions, even though the bulk of precipitation falls as snow in these resort regions. However, wind may represent a more insidious (and effective) erosive agent on bare, disturbed areas than water. Evidence indicates that wind erosion is significant and can have devastating effects on soil quality, soil nutrient cycling and long-term soil productivity (Fryrear 2000; Leys 2002; Stetler 2002a). According to Fryrear (2000): "While the transport capacity of the wind is much less than that of water, wind erosion can remove the entire nutrient-rich soil surface regardless of field size or location." In other words, while wind may not move as much sediment as water, the material that is preferentially moved by wind is the lighter soil fraction; i.e. the organic matter and fine soil particles which have a much higher propensity for negative water quality impacts than do the more coarse particles.

Thus, wind erosion can be a highly effective degradation variable that should not be overlooked. Further, wind is less noticeable but possibly more constant that water erosion. Each time a gust of wind affects a bare area, the soil moved can, over time, be significant since it will be ongoing over an entire dry season. A significant body of evidence exists that indicates that wind erosion is significant and can have devastating effects on soil and water quality, soil nutrient cycling and long-term soil productivity (Fryrear 2000; Leys 2002).

Mass Failures

Mass failure involves a downward and outward movement of soil on a slope. According to Gray and Sotir (1996) "… mass movement [of soil] involves the sliding, toppling, falling, or spreading of fairly large and sometimes relatively intact masses." (pg 20). Mass failure usually occurs along a failure plane, is the result of loss of sheer strength and is exacerbated by positive pore pressure within the soil itself.

Figure 2: This photo of the American River shows a mass failure that blocked the river for some period of time. This slide is believed to be the result of lack of vegetation from a previous fire and defoliation efforts and from water associated with a 100 year precipitation event (1997)

Mass failures have the potential to do a great deal of damage in a short period of time. Mass failures include rock falls, rotational slides, translational slides, lateral spreads, flows and creep. Mass failures may be controlled, reduced or eliminated by plant roots. For example, a mass failure on January 1, 1997 occurred along Highway 50, crossing the American River and blocking the river. The damage that occurred to beneficial uses along the river has not been financially assessed, but can only be considered major. This mass failure was partly the result of a forest fire on the upland area adjoining the river. Several houses were completely destroyed. Property damage may have exceeded several million dollars. Ecological damage is difficult to estimate.

Colluviation

Colluviation is a less well-known type of erosion that can be significant on bare areas. Colluviation is erosion due to gravitational forces. Saprolitic granite soils are especially prone to colluviation, but all bare soils on steep slopes can be affected by gravity erosion. In fact, melt freeze may act as the disturbing element that can make soil particles available for transport by gravity at some later time.

VARIABLES AFFECTING EROSION IN THE SOIL STRUCTURE

Soil structure is defined as "The combination or arrangement of primary soil particles into secondary particles, units, or peds" (Brady and Weil 1996). Soil structure may be the most important element controlling erosion in upland sites since structure depends upon a great many physical and biological elements and processes (Kay and Angers, 2002).

These interrelated elements include aggregate stability, infiltration, soil strength, pore space, soil density, water holding capacity, soil organic matter, plant growth and microbial 'activity'. Soil structure is a critical element of a site's predisposition toward erosion. According to Kay and Angers (2002): "Soil structure has a major influence on the ability of soil to support plant growth, cycle C and nutrients, receive, store and transmit water, and to resist soil erosion and the dispersal of chemicals of anthropogenic origin. Particular attention must be paid to soil structure in managed ecosystems where human activities can cause both short- and long-term changes that may have positive or detrimental impacts on the functions the soil fulfills". This statement, and the research that supports it, suggest that soil structure is of primary importance to sediment source control. When soil structure is severely disrupted (see 'drastic disturbance' above) that structure must be rebuilt if erosion is to be controlled. The following sections discuss some of the components of soil structure.

Infiltration

To the extent that water infiltrates into and through the soil, it does not run off (Radcliffe and Rasmussen 2002). In fact, runoff can be defined as the point at which water input exceeds the soil's capacity to absorb or infiltrate water (Eagelson 2002). Infiltration is influenced by a number of factors including antecedent soil moisture, soil texture, surface relief, restricting sub-surface layers, organic matter, pore space and soil density (Battany and Grismer 2000; Brady and Weil 1996; Radcliffe and Rasmussen 2002). High infiltration rates generally result in low runoff. Runoff rates and volumes are critical variables in the erosion process. The literature reported here as well as rainfall simulation underway in the Lake Tahoe area suggest that sediment source control projects will generally be successful to the extent that water can infiltrate the soils. A primary goal of erosion control projects is to develop a system of maximum, sustainable infiltration of water into the soil relative to a native and/or adequate reference site. This state of maximum infiltration is usually related to high organic matter, low-density soil and a robust, soil-plant community (Kay and Angers 2002).

Figure 3: This road cut photo illustrates lack of cover and infiltration capacity and resulting runoff.

Infiltration is heavily influenced by soil density. Each 'native' soil has a density associated with it. Generally, the more dense a given soil, the lower the infiltration rate (Frits, De Vries and Craswell, 2002). When a soil is disturbed by any type of traffic, especially when wet, that soil becomes compacted, which essentially results in a higher density, lower pore space, and a lower infiltration rate. The terms 'compaction' and 'high density' are used interchangeably although they are not always synonymous. A particular soil in its native or undisturbed state exhibits a particular density (also called 'bulk density') usually given in mass (or weight) per volume. A soils bulk density is usually given in g/cm^3, kg/m^3 or Mg/m^3. Once a site has been drastically disturbed and/or impacted with heavy equipment, that soil's bulk density increases. This results in a loss of pore space. Lack of pore space results in increased runoff and thus increased erosion (Kay and Angers 2002; Radcliffe and Rasmussen 2002).

A compacted soil is by its nature high density. Subsoil and parent material tend to also be high density by nature. In some cases where reconfiguration of a site results in subsoil being exposed, such as in a road cut or deeply incised ski run, soil density may be so high as to practically preclude infiltration. In all of these cases, some method of decompaction must take place if infiltration is to be increased to levels where plant growth can proceed and where runoff can be lessened.

Plant growth can be severely limited by compaction. For instance, Josiah and Philo (1985), in contrasting physical properties of mined and unmined soils found that the bulk density of native and ungraded soils were both 1.3 mg m-3 whereas graded, high density spoils were 1.8 mg m-3. Four years after planting, Black Walnut (*Juglans nigra L.*) trees were 35% taller and stem diameter was 31% greater in the ungraded vs the graded and compacted site. Torbert and Burger (1990) compared the survival rate of six commercially important tree species on soil of two different densities. The soil that had been left uncompacted demonstrated a 70% survival rate compared to the 42% survival rate for the compacted soil. For some species, height was almost doubled on the uncompacted site. An extensive treatment of the impacts of compaction to forest and other impacted sites can be found in <u>Forest Land Reclamation</u> (Torbert and Berger, 2000), a chapter in a highly useful book <u>Reclamation of Drastically Disturbed Land</u>, edited by Barnhiesel, Darmody and Daniels, 2000.

Depth to restricting layer

According to Torbert and Burger (2000): "Depth to a restrictive layer is an especially important physical property controlling productivity of trees [and by inference, other plants as well]. In a study to evaluate the effect of various mine soil physical and chemical properties…the most important mine soil property was rooting depth". While rooting depth is seldom considered in most erosion control projects, field experience and numerous measurements of unvegetated sites clearly suggests that shallow rooting depth is often associated with lack of vegetative cover.

Two considerations connecting rooting depth and erosion are:

1) Plants need a certain quantity of available nutrients and water. Water especially, is associated with the volume of pore space in a soil. A restricting layer tends to limit the amount of pore space in a soil, thus limiting water availability; and

2) When water reaches a restricting layer, the infiltration rate is slowed, thus tending to saturate the soil. Two things can then occur. First, more water will flow over the surface as runoff and second, positive pore pressure in the soil and the different soil densities can lead to mass movements, such as landslides.

Nutrient Cycling/Soil Organic Matter

Soil organic matter has been linked to both establishment and persistence of plant communities in the Lake Tahoe basin and elsewhere (Claassen and Hogan 2002; Baldock and Nelson 2002; Reeder and Sabey 1987; and Bradshaw 1997) as well as an increase in the soils ability to resist erosion. Torri and Borselli (2000) have found that "increasing organic matter content makes aggregates more resistant to sealing and consequently decreases runoff and erosion." And further "… those relationships indicate that soils with good granular structure (high Fe oxide and organic matter content) are less erodible. (pg G-189)". McBride (1994) summarizes the functions of organic matter as follows: "In partnership with the clay fraction, organic matter has an extremely important influence on the chemical and physical properties of soils. Critical and beneficial functions of organic matter include:

1. Maintenance of good pore structure accompanied by improved water retention
2. Retention of nutrients (e.g. Ca^2+, Mg^2+, K+, NH^4+, Mn^2+, Fe^3+, Cu^2+) by cation exchange
3. Release of nitrogen, phosphorus, sulfur, and trace elements by mineralization, the microbial process by which organic compounds are decomposed and carbon dioxide is released.
4. Absorption of potentially toxic organics (pesticides, industrial wastes, etc.).

Aggregates

According to Cambardella (2002), "A soil aggregate is formed when closely packed sand, silt, clay and organic particles adhere more strongly to each other than to surrounding particles. The arrangement of these aggregates and the pore space between them is referred to as soil structure. Soil aggregates are held together by three classes of binding agents: 1) humic material; 2) polysaccharides (organic sugars); and 3) temporary elements (roots, root hairs and fungal hyphae) (Tisdale and Oades 1982). Soil aggregate formation has been shown to be dependent upon soil organic matter content (Baldock and Nelson 2002; Blackmer 2000; Wilkinson, Grunes, and Sumner 2000). Aggregates in the soil are closely linked to the ability of a site to resist erosion (Kay and Angers 2002).

Soil aggregate formation has been shown to link to soil organic matter content (Baldock and Nelson 2002; Blackmer 2000; Wilkinson, Grunes and Sumner 2000; Kay and Angers 2002) as well as an increase in the soils ability to resist erosion as well as increased microbial populations whose production of extracellular polysaccharides enhances soil structure. These data suggest that organic matter plays a number of very specific roles in reducing erosion and is of critical importance for encouraging aggregates.

Surface Cover/Mulch

Soil surface cover plays a critical role in not only erosion reduction but in other ecosystem processes as well. According to Pritchett and Fischer (1987): "Plant and litter cover is the greatest deterrent to surface erosion. The tremendous amounts of kinetic energy expended by falling rain are mostly absorbed by vegetation and litter in undisturbed forests. Disturbances caused by logging and other activities reduce infiltration rates and increase surface runoff and erosion" (pg 304).

Surface cover provides the following services:

- Reduces raindrop force (splash detachment);
- Reduces surface flow velocities (sheer detachment of soil particles by both wind and water);
- Reduces evaporation (water loss reduction);
- Reduces radiation influx and efflux;
- Increases soil nutrients (some mulches) (Woods and Schuman1986);
- Increases seed germination at some levels (Molinar, Galt and Holechek 2001);
- Protects soil from sealing and pore clogging (Singer and Blackard 1978).

Grismer and Hogan (in prep) show that mulches alone could reduce soil erosion from bare slopes by an order of magnitude. However, the type, age and fiber length of the mulch material is important.

Plants

Plants play an important role in erosion processes. Plants are closely linked to the elimination or reduction of erosion and have commonly been employed as the chief line of defense against surface erosion. Gray and Sotir (1996) describe the various services provided by plants including surface protection, surface and subsurface reinforcement of the soil and influence on subsurface hydrology. They describe differences between woody and non-woody plants as well as provide limited sheer strength values for some plants. The role of plants cannot be understated. Since these roles are so complex, we refer to Gray and Sotir as well as other references where these roles are discussed in detail. Plants provide an 'indirect' service by providing surface protective mulch. Torri and Boreselli (2000) state, "…the most effective action (of plants) is due to dead leaves and branches laying on the soil surface (mulch)." This mulch, as well as senescent plant roots, play a major role in establishing and maintaining the soil nutrient cycle (Baldock and Nelson, 2002; Pritchett and Fisher 1987; Paul and Clark 1989). Plant roots are a host to soil microorganisms and provide some of those organisms with a source of energy and nutrients (McBride 1994; Paul and Clark 1989; Reeder and Sabey 1987; Smith, Redente and Hooper 1987).

While plants do play a number of essential roles in stabilizing soil and reducing erosion, plants alone do not always limit erosion to acceptable levels (Elliot 2002; Zhang 2002). Grismer and Hogan in recent rainfall simulation experiments on a range of cover types and amounts throughout the Tahoe region, found that plant cover did not always correlate with sedimentation rates and in fact, found that some sites with extremely high cover levels produced an extremely high erosion rate, similar to adjacent bare plots (Hogan 2004).

Soil Microbial Communities/Mycorrhizae

Microbial 'activity' is the chief driving force behind most soil function (McBride 1994; Paul and Clark 1989; Reeder and Sabey 1987; Huang and Schnizer 1986; and Whitford and Elkins 1986). Microbial populations are closely linked to and dependent on soil organic matter and soil quality. Microbes contribute to nutrient cycling and availability, aggregate formation, erosion resistance, water-holding capacity, disease resistance and so on. There are a number of microbial 'types' that coexist in the soil. A great deal is known about soil microbes and an even greater amount remains to be discovered. Soil microbes are grouped into broad categories of bacteria, actinomycetes and fungi. Soil microbial communities are known to convert most nutrients from an organic form into a plant available form (Blackmer 2000; Killham 1994; Paul and Clark 1989; Tisdale and Oades 1982; Tisdale et. al 1993; Buxton and Caruccio 1979) In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994 and Allen 1991). These fungi are categorized as Mycorrhizal.

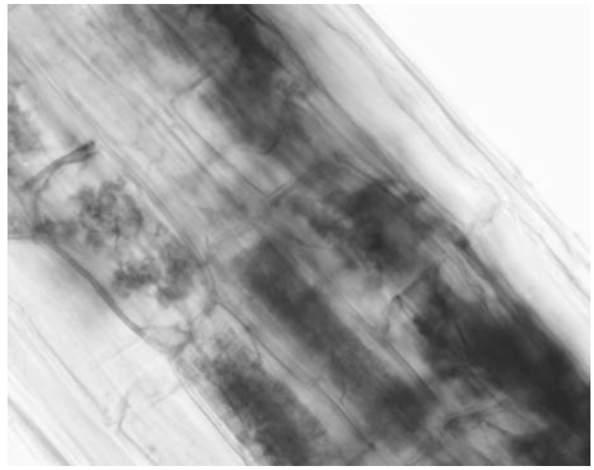

Figure 4: This scanning electron micrograph image shows mycorrhizal colonization in a plant root (photo courtesy of Dr. Vic Claassen, UC Davis).

Mycorrhizae, which means 'fungus roots' are an important element of the soil ecosystem. Mycorrhizae have received a great deal of attention with respect to their function and potential for use in disturbed site revegetation (Allen 1992). Mycorrhizae are a specific type of fungi that form a symbiotic relationship with plants. They are one part of an incredibly complex ecosystem of soil microbes.

Surface Roughness

Surface roughness is often overlooked as a significant variable in erosion (Torri and Boreselli, 2000; Batanny and Grismer, 2000). Surface roughness helps determine the velocity at which overland flow can occur, thus influencing both flow velocities and infiltration. Further, surface roughness is often associated with soil clods or aggregates and thus suggests soil stability, at least in an undisturbed and/or stable soil.

Soil Surface Sealing/Pore Clogging

Surface sealing and pore clogging are two potentially related processes. When infiltration of water occurs, fine clays, silts, organic matter and other elements can contribute to the clogging of pores. This process is especially related to splash detachment of fine sediments and subsequent redistribution. In some cases, these fine sediments are redistributed across the soil surface and subsequently dry into a hydrophobic layer called a soil crust. In other cases, this material makes its way into the soil and fills soil pores. In either case, the result is loss of infiltration and subsequent increase in overland flow and related erosion (Moody 2002). Over time, pore clogging and surface sealing may reduce infiltration to a level similar to highly compacted soil. This is an insidious issue in 'settling ponds'.

SECTION THREE: TREATMENTS FOR SEDIMENT SOURCE CONTROL

SECTION OVERVIEW

This section describes various 'functional' tools that can be used to develop a sustainable, robust erosion control program. The term 'functional' refers to the various functions that exist in an ecological system. Many planners attempt to establish grasses and other plants on a highly disturbed site much as one would plant a lawn or pasture. However, recent research has clearly indicated that vegetation alone may not always be adequate to control erosion (Grismer & Hogan 2004; and in press). To create a self-sustaining soil-vegetation community, this section addresses the restoration of actual functions that have been disturbed or destroyed during disturbance.

A great many erosion control projects are designed and implemented with the project proponent assuming that specific BMPs (Best Management Practices) have been tested and 'proven', or that information gathered in various publications or conferences will actually perform as indicated. Unfortunately, that is not usually the case. This section provides tools used in site-specific erosion control and restoration implementation plans.

DEFINING SUCCESS AS IMPROVING FUNCTIONS

All erosion control treatments define success either implicitly or explicitly. How we define success will determine how we approach a project. For instance, if we envision a successful erosion control project outcome as primarily a well-vegetated area, then we are likely to focus on 'revegetation' as our primary treatment. We will seed, fertilize, possibly mulch and irrigate in order to establish that vegetation. Erosion itself may actually take on a secondary level of importance. As an example, some erosion control projects have actually produced erosion (sheet erosion or rills) as an outcome of irrigation, used in an attempt to establish vegetation on treated areas. Some of these sites have been considered 'successful' because grass had been established (Hogan, personal observations, summer 2003, 2004, at 5 Sierra ski resorts).

If we define success in terms of function, rather than form (how a site looks), it is likely that we will be much more accurate in assessing 'success'. In other words, we will be able to determine how a project is working rather than simply how it looks. According to Cummings (2003), the ability to restore function within the soil-plant ecosystem is likely to be the most powerful approach we can take to control sediment at its source. Cummings suggests that restoration of function within a disturbed system should be a primary goal. The usefulness of this concept can be seen in some projects where surface treatments are aimed at plant growth as a primary objective. Recent research on ski runs and highway road cuts has shown that, while it is possible to actually force plants to grow, these plant-dominated projects do not automatically equate with greater erosion control since runoff can still be quite high (Grismer 2004).

According to Cummings and others, the main functions of concern are:

1) Hydrologic function (infiltration, storage, transfer of water into and through the soil);

2) Nutrient cycling (cycling of nutrients within and through the soil); and

3) Energy capture (processing, storage and transfer of energy from the sun as well as capture and transfer of water energy within and through the watershed).

For example, if water infiltrates into the soil, it will move through the watershed more slowly, thus resulting in a lower runoff rate as well as lower volume and velocity of water in the streams. This attenuation of energy will lower overall erosive forces. Without restoring soil hydrologic function, including infiltration, the goals of erosion control are not likely to be met, even though a site may support plant growth (at least as long as fertilizer and irrigation are applied).

Energy capture may be described in two contexts: 1) energy captured and stored in the biota or living things such as plants and soil flora and fauna; and 2) energy stored as water within the soil. Energy capture describes the plant community as well as links to the hydrologic function within a project area. Beyond simply describing plants as a 'form', this approach recognizes the plants function within the ecosystem: they store and then transfer energy to the soil and to animals as food.

This approach also discusses the energy function of the water within an ecosystem as well. For instance, a storm and/or runoff hydrograph represents an energy distribution graph. A hydrograph with a large peak early in the runoff cycle has a much higher probability of erosion than a lower peak later in the runoff cycle. This is also known as peak flow attenuation. A high peak hydrograph describes a much more erosive runoff force than a low peak hydrograph. Water that is stored in the soil as energy is available for plant growth throughout the growing season.

We therefore focus on three main functions: hydrologic function, nutrient cycling and energy capture, for planning and implementing treatments. By maximizing these three functions, soil will tend to remain in place and water within the watershed will tend toward a more natural or background behavior.

THREE COMMON TREATMENT INDEXES

While most sediment source control efforts focus on liquid water erosion, many of the same processes used to control liquid water erosion are also effective for wind and frozen water-caused erosion (McCool 2002; Fryrear 2000; Tibke 2002). According to Reichert and Elemar (2002) "Water erosion is caused basically by raindrop impact and runoff of excess water, thus erosion and sedimentation control strategies must be based on covering the soil against raindrop impact, increasing water infiltration to reduce runoff generation and increasing surface roughness to reduce overland flow velocity."

The same techniques that are used to protect the soil surface against raindrop impact, namely mulch and live plants, are also effective for protection against wind erosion (by deflecting wind from the soil surface) and for protection against frozen water erosion (by insulating soil against freeze thaw and by providing additionally surface roughness for snow melt). Traditionally, live plant cover has been considered of primary importance in erosion control. However, a great deal of research has shown that total ground cover, and especially mulch, provides the most critical short-term impact or protection (Zhang 2002; Elliot 2002; Grismer and Hogan, in press).

There are an extremely large numbers of attributes that actually define a site's ability to control erosion, such as the extent of the microbial community, particle size distribution, plant type, and so forth. However, the three most accessible attributes that we often choose to serve as indices or site indexes for erosion resistance, given that they increase sediment control in areas with water and wind pressures are:

1) cover (plant and mulch);

2) soil organic matter and associated nutrients; and

3) levels of infiltration.

SOIL NUTRIENT TREATMENT ISSUES

Nutrients are critical for both plant and microbial growth in the soil. There are a broad range of both macro (N,P,K), secondary (Ca, Mg, S) and micro (Zn, Fe, Mn, Cu, B, Mb, Mo, Cl, Ni) nutrients. Typically, in the Sierra Nevada and other western mountain ranges (in non-mined sites) macro and micro nutrients tend to be adequate on disturbed sites, except N. However, it is difficult to generalize about adequacy of most nutrients in disturbed wildland settings. Therefore, the ability to gather soil nutrient data from surrounding 'reference' sites will usually be an important step in understanding what is required in a native or self-sustaining system.

Nitrogen (N) is clearly recognized as the most important or generally most limiting nutrient involved in plant growth on disturbed sites (Marrs and Bradshaw 1993; Palmer 1990; Reeder and Sabey 1987; Bradshaw et al. 1982; Bloomfield, Handley, and Bradshaw 1982; Wilkinson, Grunes, and Sumner 2000; Palmer 1990; Bloomfield, Handley, and Bradshaw 1982; Cummings 2003). N is used in the greatest quantities by plants and can be very mobile in mineral form.

While N is known to be limiting, caution should be exercised when determining which material may be needed to replace N or other nutrients. Many water bodies, such as Lake Tahoe, are known to be P (phosphorus) limited. If a fertilizer or amendment contains relatively high levels of P and the soil contains adequate P, additions may result in loss of P from the soil into nearby waterways – a water body pollutant. Therefore, knowledge of both existing soil nutrient conditions as well as release characteristics of the fertilizer or soil amendment itself is important for effective use that minimizes runoff-pollution prevention.

N can be a limitation in both agricultural and wildland ecosystems. An important difference between these two types of ecosystems is that agricultural systems ('dose-response') are designed to receive an input (fertilizer), and produce a response (plant growth) that is then removed from the system. The following season, the same cycle is repeated. Wildland systems, on the other hand, are self-sustaining. That is, they cycle most of their nutrients internally. In a pine forest, for instance, pine needles fall to the ground, are broken down by microbial activity and eventually turn into nutrients for both plants, microbes and macrobes. Therefore, when planning and implementing an erosion control project, an understanding of the soil nutrient content (load) is critical. In preparing project plans, it is important to understand three things:

1) What amount of nutrients are in the project site soil?

2) What amount of nutrients should be in the soil (measuring a reference site and/or using data from similar sites)? and

3) What amount and what type of nutrients need to be added to assure a self-sustaining system?

Several studies suggest that a certain level of nutrients, especially N, must be present in the soil before an adequate plant cover can be established and maintained (Claassen and Hogan 2002; Bradshaw 1997; Li and Daniels 1994; Reeder and Sabey 1987; Bradshaw and Chadwick 1980). Research on disturbed sites in the Lake Tahoe Basin, California and Nevada, showed a correlation between certain nutrient pools, especially nitrogen, and plant cover on previously disturbed sites (Claassen and Hogan 1998). Therefore, knowing current conditions before planning will allow the planner to specify the appropriate amount (and type) of nutrient additions.

Bradshaw et al (1982) discussed the development of N cycling on mined land. They suggested that a pool of at least 1000 kg/ha-1 must be accumulated, after which N cycling by mineralization, plant uptake and litter fall will support a self-sustaining ecosystem. This value compares well with that suggested by Claassen and Hogan (Claassen and Hogan 2002) who found that well vegetated, previously disturbed sites in the Lake Tahoe Basin, were related to a pool of at least 1250 kg/ha-1 total N.

While N is understood as a critical limiting nutrient in most terrestrial semi-arid ecosystems, and N is largely derived from organic matter in those ecosystems, the capacity for the total N contained in that organic matter to mineralize is not consistent or well understood (Baldock and Nelson 2002; Blackmer 2000). Reestablishment of nutrient cycles on disturbed sites is seen as a primary cornerstone in the successful re-creation of a sustainable terrestrial ecosystem capable of reducing erosion, improving water quality, enhancing wildlife habitat and improving other beneficial uses (Haering, Daniels, and Feagley 2000; Macyk 2000; Marrs and Bradshaw 1993; Palmer 1990; Reeder and Sabey 1987; Dancer, Handley, and Bradshaw 1977; Cummings 2003; Bradshaw et al. 1982; Bloomfield, Handley, and Bradshaw 1982; Dodge 1976). Woodmansee et al. (1978) reported that N deficiency can affect the long-term stability of a site by limiting plant growth, thereby increasing erosion from that site.

ORGANIC MATTER TREATMENT ISSUES

Soil organic matter drives a number of processes in the soil, as discussed in previous sections. Powers (1990) suggested that a decline in forest productivity is linked directly to losses of soil organic matter. It thus may be one of the most important elements of soil function. Noyd et al.(1996) reported that compost had a primary impact on reestablishment of both plant communities and mycorrhizal fungi colonization on taconite mine spoils in the Mesabi Iron Range in Minnesota while arbuscular mycorrhizae (AM) inoculation played a secondary role. Johnson (1998) suggested that manipulating edaphic factors through additions of soil organic matter may be more cost effective on low P sites than large scale mycorrhizal inoculation. These edaphic factors include adequate organic matter in the soil and many of the connected elements, as mentioned above.

The inclusion of organic material in a depauperate (low nutrient) soil may provide additional benefits beyond nutrient additions, such as increased water holding-capacity, increased microbial activity (enhanced cycling of pre-existing nutrients) increased infiltration rates, and a higher cation exchange capacity (Brady and Weil 1996). Soil organic matter has been linked to both establishment and persistence of plant communities in the Lake Tahoe basin and elsewhere (Claassen and Hogan 1998); (Baldock and Nelson 2002; Bradshaw 1997; Woodmansee, Reeder, and Berg 1978;) as well as an increase in the soils ability to resist erosion. There are a number of types of organic matter including compost, wood chips, manure and others. Each has its own strengths and weaknesses and should be considered carefully before use, especially for amounts and release rates of nitrogen and phosphorus.

FERTILIZER TREATMENT ISSUES

The use of fertilizer for erosion control projects has been a standard practice for many years. Essentially, fertilizer is used to make up for inadequate amounts of nutrients in the soil (Soil Improvement Committee 1998). Much of the information and the approach to fertilizer use comes from agricultural research. Much less research has been done on wildland system restoration. However, some work has been done by Bradshaw and others in mine reclamation to focus on rebuilding and re-capitalizing the nitrogen cycle in 'derelict' or drastically disturbed sites. These researchers generally found that adequate N cycling was directly linked to organic matter in the soil (Roberts R. D. et al 1980; Bradshaw, Marrs et. al 1982; Bloomfield, Handley et. al 1982; Marrs & Bradshaw 1982; Woodmansee, Reeder et al. 1978). Further, Classen & Hogan (2002) found that adequate organic matter and mineralization of the N in organic matter was directly linked to plant growth. While some of this research has been available since 1980, few findings have been incorporated into ski area work.

Bradshaw and others suggest that rebuilding of the nitrogen cycle is the underpinning of most reclamation or restoration on drastically disturbed land. Reeder & Sabey (1987) and many others support the importance of this approach. Their findings clearly suggest that fertilizers alone are unlikely to rebuild these soil-plant systems to adequate levels of N in a reasonable time unless a very careful application regime is instituted. Yearly applications may increase nutrients to the point of self-sustainability, as Ray Brown was able to show on a mine site in Idaho. However, 25 years were required to do so. In this project, cost was not evaluated but estimates of labor alone could be as high as $25,000 (Brown and Johnson 1978).

When using fertilizers, it is essential to understand their strengths and limitations and not expect fertilizers alone to completely regenerate self-sustaining nutrient cycling (Tisdale et al 1993). Fertilizers will be seen as part of an overall package of treatment. It is also critical to understand what type and how much fertilizer is actually needed in any particular situation so that under or over application does not become a problem (Tisdale et al. 1993; Soil Improvement Committee 1998).

Fertilizers come in many forms and nutrient amounts. The two most common fertilizers are the 'mineral' and the organically based fertilizers. Further, some mineral fertilizers are coated so that the nutrients are released more slowly. Specific information on fertilizers can be found (Tisdale et. al 1993; Soil Improvement Committee 1998).

MYCORRHIZAE TREATMENT ISSUES

Mycorrhizal fungi play an important role in most ecosystems. Mycorhizzal fungi are a group of fungi that have the ability to form a relationship with certain plants in an apparently mutualistic relationship. Mycorhizzae can be considered as an important subset of soil microbial components.

A broad range of information about mycorhizzal physiology, morphology, classification etc can be found in Walling, Davies and Hasholt 1993; Paul and Clark 1989; and Killham 1994.

In terms of the benefits of mycorrhizae, there is little doubt that these types of fungi play a critical role in many types of plant growth. Paul and Clark and Killham discuss the myriad of benefits associated with the range of mycorrhizal fungi. The two types of mycorrhizae that are of chief concern in wildland systems, especially relative to restoration, are the vesicular-arbuscular subgroup of the endotrophic mycorrhizae and the ectotrophic mycorrhizae, which form relationships with temperate trees and shrubs (Paul and Clark 1989). Endotrophic mycorrhizae are found on about 90% of the worlds' plants (Israelsen 1980) and so are of critical concern.

The microbial community within a soil are known to drive conversion of most nutrients from an organic form into a plant available form (Paul and Clark 1989; Killham 1994; Tisdale et al. 1993; Buxton and Caruccio 1979; Killham 1994; Tisdale et al. 1993; Buxton and Caruccio 1979). In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994). A great deal of attention is currently being placed on mycorrhizal fungi and specifically, use of commercial, non-native or non-indigenous inoculum. Noyd (Noyd et al. 1997) and others reported that compost had a primary impact on reestablishment of both plant communities and mycorrhizal fungi colonization on taconite mine spoils in the Mesabi Iron Range in Minnesota while arbuscular mycorrhizae (AM) inoculation played a secondary role.

Johnson (1998) in studying plant response to mycorrhizal inoculation across a phosphorus gradient reported that inoculation with arbuscular mycorrhizal (AM) fungi reduced growth at high soil P levels. This finding is relevant to Tahoe and Sierra Nevada soils that tend to be high in P (Rogers 1974), suggesting that AM inoculation may not play an important role and may, in fact, reduce plant growth on some revegetation sites. This finding is further supported by an unpublished study of a variety of treatments (Longenecker, Senior thesis) on Tahoe granitic soil, including inoculation with non-native (cultured) mycorrhizae. Measurement of growth rates in a sixty day experiment showed that soil inoculated solely with mycorrhizae resulted in a growth rate lower than the control, while soil with compost and organic fertilizer, resulted in growth rates over twice as high as either the control or the inoculated pots.

Further, Johnson (1998) suggested that manipulating edaphic factors through additions of soil organic matter may be more cost effective on low P sites than large scale inoculation. In support of this approach, Sylvia (1990) reported that, after initial infection by vesicular arbuscular mycorrhizae (VAM) on plants used in a mine reclamation site in White Springs, Florida, there was no plant effect at 18 months and that VAM inoculation had no effect on transplant survival. These soils were low in nutrients, thus supporting the nutrient addition findings of Noyd, Pfleger and Norland (1996), Johnson and others.

In another study Noyd et al (1997) reports that adequate rates of compost added to taconite mine tailings produced biomass equivalent to or surpassing a native tallgrass prairie in three years. At the same time, organic matter accrual increased and litter breakdown rate decreased, inferring long-term plant community sustainability. In a greenhouse study, Stahl et al (1998) discuss the capacity of VAM-inoculated Big Sagebrush to better withstand drought than non-inoculated plants. However, the substrate used was collected from an undisturbed, nutrient-adequate site, further supporting the adequate nutrient concept. Weinbaum and Allan (1996) in a reciprocal transplant study between San Diego and Reno, showed that non-local mycorrhizal inoculum always declined at the exotic site and with exotic hosts, arguing for both locally-collected inoculum and local plant source.

Plant treatment issues

Plants play an extremely important role in practically all ecosystems. Plants are linked to and supported by the soil resource/ soil community. For many years, researchers and erosion control writers and practitioners have emphasized the plant or vegetative component of erosion control in revegetation and restoration projects (California Tahoe Conservancy 1987; U.S. Department of Agriculture 1982; Nakao 1976; Leiser et al. 1974). Plants play a great many roles in restoration and erosion control, especially on disturbed sites. Plants are closely linked to the elimination or reduction of erosion and have commonly been employed as the chief line of defense against surface erosion. However, while plants play an essential role in stabilizing soil and reducing raindrop impact, they do not always limit erosion to acceptable levels. (Elliot 2002; Zhang 2002). We suggest that by linking the plant and soil elements, a more effective outcome will be produced.

A healthy, robust soil will be a critical issue for planting of any kind. Drastically disturbed soil will have very different attributes from a slightly or non-disturbed site. Reestablishment of a sustainable plant community on severely disturbed upland sites in the Sierra Nevada has proven difficult (Erman and Others 1997; Leiser et al. 1974).

Aside from surface stabilization, plants also contribute to subsurface stabilization. An increase in root biomass typically results in an increase in physical soil stabilization due to sheer and tensile strength (Gray and Sotir 1996). This fact is useful in ski areas to counter some county or other 'engineering' agencies that may require ski runs to be compacted in order to provide soil strength. However, when soil is compacted, infiltration is decreased and plant roots cannot penetrate easily, thus reducing plant growth to minimal levels see ('Infiltration, Soil Density' section, above). Further, plants have been used successfully in the Lake Tahoe and Truckee areas to successfully hold loose soils of up to 1:1 slopes (Cave Rock Report, in preparation).

One additional consideration for plant use is that claims made by suppliers, may not live up their billing, given that site conditions vary widely.

Mulch Treatment Issues

A great deal of information exists regarding the effectiveness of mulch to control erosion. Agassi (1996) states "Mulching is a very efficient means to dissipate raindrop impact and to control the ensuing soil surface sealing, runoff and erosion. Mulching can also reduce evaporation of rainwater and overhead irrigation water. Therefore, mulching can be a vital factor in improving water use efficiency". Mulch provides a number of 'services'. These services are listed in the following Table 2:

Table 2: Mulch Services

Service	Description	Notes
Surface protection-rain	Protects soil surface from raindrop splash detachment	
Surface protection-wind	Protects soil surface from detachment and transport of soil particles by sheer forces	
Overland flow reduction	Reduces overland or surface flow of water by creating a maze of 'mini-dams'.	Longer fiber length provides better protection; Blown on mulch results in better soil surface contact
Temperature protection	Mulch reduces solar input to the soil by reflecting solar energy.	The color of a particular mulch plays an important part in this process. Darker mulch absorbs more heat energy, for instance.
Evaporation protection	Mulch reduces evaporation by reducing surface temperatures as well as by creating a physical barrier	
Nutrient addition	Organic mulches contain carbon and other organic nutrients that can enhance both organic matter and nutrients in the soil	Nutrient and energy additions are variable and depend upon the material. For instance, straw is known to contain very little C and N while pine needles can be much higher. Wood chips may lock up N but contain high amounts of C.

In the Tahoe Basin, an ongoing study by Grismer and Hogan (in submission) found that mulches can reduce sediment delivery by an order of magnitude. Edwards and Burney (1987) found that mulch minimized effects of both compaction and freeze thaw on a range of soils (silt, sandy loam, fine sandy loam). Battany and Grismer (2000), showed that in a California vineyard, soil loss was linked to soil cover.

Pine needles

Pine needles have been used in the Lake Tahoe Basin and elsewhere as a surface mulch since 1992. However, little research has been done on pine needle effectiveness. Pannkuk and Robichaud (2003) studied pine and fir needle cast following fires on both volcanic and granitic soils and found that a 50 percent cover of Douglas fir needles reduced interrill erosion by 80 percent and rill erosion by 20 percent. A 50 percent cover of ponderosa pine needles reduced interrill erosion by 60 percent and rill erosion by 40 percent. (Wright, Perry, and Blaser 1978).

Pine and fir needles offer advantages over some short-lived mulches such as straw since they last anywhere from two to ten times as long, thus providing services over longer periods of time. Grismer and Hogan have been assessing pine needle effectiveness for a number of years. Reports currently in press or in submission describe the positive effects of pine needles on plant growth and erosion reduction (Caltrans Demonstration and Development Report, in preparation by Grismer & Hogan). They have shown that some of the highest infiltration rates, as well as the highest plant cover rates on restoration sites, have occurred under a pine needle mulch. Modeled after native forest surface cover, the use of pine needles has shown very promising results.

TILLING TREATMENT ISSUES

Removal of compaction and/or reduction of soil density is a critical component of restoring hydrologic function to soil. Froehlich and McNabb (1984) showed that compaction may last up to 30 years and can reduce stand growth in Pacific Northwest forests by up to 15%. Tillage of compacted soil can be effective in reversing compaction. Luce showed that on a highly compacted road that had been ripped, saturated hydraulic conductivity can be up to 35 mm/hr, or approximately half of the natural background. However, Luce (1997) also suggested that this rate represented a significant increase in infiltration and would effectively reduce runoff and thus erosion during rainfall events of over 1" per hour.

Grismer and Hogan measured infiltration rates of fully treated (wood chips tilled into a highly compacted soil) of over 4 inches per hour on a Tahoe area ski run (Hogan 2004b). Torbert and Burger (2000) reporting on research by Larson and Vimmerstedt (1983), stated that compaction is likely the most important mine reclamation problem in need of solution. They stated that compaction is caused during several steps of reclamation construction such that soil bulk density is reduced to root limiting levels.

ECONOMIC CONSIDERATIONS IN TREATMENTS

An extremely important consideration in designing and implementing a restoration, erosion control or revegetation project is the cost. One approach that needs further study is the 'cost over time' or 'cost per unit time' aspect.

The cost of implementing an erosion control project is often measured as the cost of applying material to the project area. However, if we regard the replacement of function to that site as a primary goal and add the element of time, the question becomes: "How well does this project function and for how long?" For instance, if straw mulch is used and lasts two seasons and costs $1000/ac compared to pine needle mulch which may cost $2500/acre but lasts five seasons, then the actual cost would be exactly the same per year effectiveness. More cost effectiveness assessments will be critical to determining the actual costs of projects, not just the application cost. Many projects in the Lake Tahoe Basin have been re-treated using the same, relatively inexpensive techniques (hydroseeding, no soil preparation) two and three times and still have not performed adequately (personal communication, Jason Drew- NRCD, Joe Pepi-California Tahoe Conservancy; Larry Benoit-Tahoe Regional Planning Agency). At that point, the question becomes: "How many times do you apply something that doesn't work before realizing that resources are not being spent effectively?"

Conclusion

Disturbance and erosion need to be considered in a holistic, systemic and functional context in order to develop effective strategies to reduce or control that erosion (Dudley and Stolton 2003). If the 'system' within which erosion takes place is ignored, erosion control measures are unlikely to succeed over the long term. It would be useful to present information and techniques that would clearly show how to successfully stop erosion. However, the paucity of information has led to the creation of the CAREC plot sites.

While a great deal of information has been published about the control of erosion, little of that information provides a complete picture of what is required at each site. Further, most erosion-related research tends to be single variable manipulation studies such as mulch, seed, fertilizer, plant type and so on (see "State of Erosion Control Knowledge" above). Beyond the single variable consideration, most studies are also point in time studies, which means they don't tend to measure results over a multi-year period. This type of information can be incomplete at best and misleading at worst. Field practitioners must deal with multiple variables and do so over several seasons.

Based on this Literature Review the following information gaps have been identified as key areas for additional inquiry, research and documentation in alpine areas:

- The need for better quantification of treatments vs. modeling or guesswork
- Mulches
- BMP effectiveness, especially biological and soil-based BMPs
- Runoff simulation
- Seeding rates
- Tilling depths
- Soil sheer and tensile strength measurements
- Compaction and runoff correlation
- Large scale soil loosening effectiveness and efficiency
- Freeze thaw protection with mulch and organic matter
- Improved calibration of the runoff ("C") coefficient for watershed hydrology models

This situation presents us with both restrictions and opportunities. We are restricted by a lack of complete knowledge on effective erosion control treatments in disturbed alpine areas. However, we are offered the opportunity to gain missing knowledge on our own projects through the use of an adaptive management approach (see Guiding Principles). CAREC is committed to improving our understanding of effective sediment source control treatments in ski resorts, and enhancing all three sections of this Sediment Source Control Handbook. By working together and building on our field trials and knowledge base we can have a meaningful impact on erosion control and watershed health throughout the Sierra Nevada.

CALIFORNIA ALPINE RESORT ENVIRONMENTAL COOPERATIVE

SEDIMENT SOURCE CONTROL HANDBOOK PART III

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